Design and Development of a Turbine Flume Testing Rig

Undergraduate Honors Thesis

Presented In Partial Fulfillment of the Requirements for Graduation with Distinction in

Mechanical Engineering of The Ohio State University

By

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2021

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Abstract

With fossil fuel usage increasing to accommodate expanding electricity consumption around the world, the production of electricity through renewable means has become a viable avenue for expansion. Hydropower represents one of the possible means of producing electricity. Due to the high costs, long construction times, and environmental impacts of damming rivers, private interests have turned their focus to preexisting low head dams that could be powered with the addition of hydropower applications. Although these hydropower applications offer the possibility of commercial success, testing facilities lack the capability to accurately test and easily alter the testing configuration to allow for numerous designs or concepts to be tested.

This thesis offers a potential solution to the problem of testing rigs for widespread implementation. Following inspiration both from the engineering design process and product design and development, the problem was identified, design parameters were laid out, and initial sketches were created. Following initial idea generation concept screening and scoring helped to eliminate designs not worth pursuing further. Modeling of the cross functional designs occurred using SolidWorks. Numerous iterations were considered during the 3-Dimensional modeling phase. With a design chosen, optimization of the design began with a focus on reducing labor and costs where possible. Next the components sourcing budgets was outlined. Lastly, machining and assembly instructions were created.

With a completed Testing Rig, The Ohio State University will be able to alter parameters for testing, such as the height of the water, the shape and size of the weir, as well as the angling of water flowing into and out of the turbine.

Acknowledgements

I would like to thank Dr. Belloni for the ability to work in her research lab. I would like to thank Dr. Stagge for serving on my thesis committee and allowing for the testing rig outlined in this thesis to be implemented upon completion. Lastly, I would like to thank my fiancé Emily for showing me light when surrounded by darkness.

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Nomenclature

Acronyms	
WCFT	Williams Cross Flow Turbine
NPD	Non-Powered Dam
CFD	Computational Fluid Dynamics
Symbols	
p	Pressure
ρ	Density
g	Gravity
h	Height
A	Area
P	Force
L	Length
M_{AB}	Bending Moment
σ	Stress
c	Distance for Center to Point of Highest Stress
I	Moment of Inertia
b	Length of Object Under Stress
d	Depth of Object Under Stress

Chapter 1

Introduction

Chapter 1 serves as an introduction to the project; it looks at the potential for low head hydro turbines to be utilized in low head dams and a brief introduction of the testing facilities currently available. This chapter will discuss the design approach as well as why it was undertaken. The chapter also includes a short summary of the remaining chapters in this thesis.

1.1 Background

With the threat of global climate change accelerating and stores of fossil fuels becoming depleted, research into more environmentally friendly forms of energy has increased. The United States Department of Energy has documented an increase in the number of active hydropower projects both domestically and abroad over the past two decades (US Hydropower Market Report, 2021) . It is safe to assume that as development of hydropower projects continues, interest in small scale hydropower will become of higher importance. Currently 54,391 low head, non-powered dams exist in the United States. The same report conducted by Hadjerioua et al. (2012) found that by electrifying the top 100 of these NPDs would produce eight GW of electricity for the United States. Development of turbines to accommodate these low head dams has been started and academic research has been conducted at The Ohio State University.

Possibilities for production of low head hydro power include traditional modes such as the utilization of waterwheels or Archimedes screws. Research conducted by Muller and Wolter have shown that in experiments using breast shot water wheels efficiencies of around 60% have been achieved (Wolter, Christian 2004). Similarly, research conducted by Yoosefdoost and Lubitz showed the Archimedes screw turbine could be capable of producing around 60%

efficiency (Yoosefdoost, Arash & Lubitz, William, 2020). In addition, companies such as GE Renewables, Voith, and Natal are working on hydrokinetic turbines to generate electricity in areas where low head dams are prevalent. One such company is kWRiver, with its Williams Cross Flow Turbine. Researchers at Central State University have shown the potential of using the Williams Cross Flow Turbine for generation of power on low head dams. Numerous researchers at Ohio State University have worked to improve the efficiency of the turbine so that low head hydro power can become a reality.

1.2 Williams Cross Flow Turbine

Initially designed as an extension of waterwheel technology, the Williams Cross Flow Turbine has evolved to a fully submersible cross flow turbine that is specially designed to sit at the foot of a weir or dam (Williams & Kling, 2017). Figure 1.1 below shows the Williams Cross Flow Turbine.

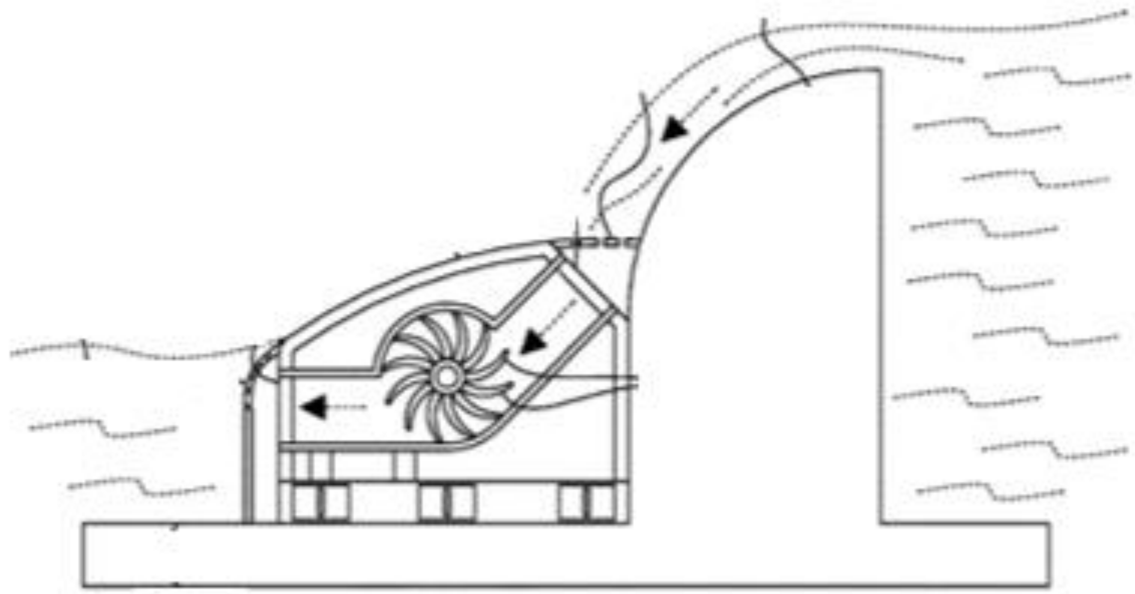

Figure 1.1 Williams Cross Flow Turbine (Williams & Kling, 2019)

The Williams Cross Flow Turbine includes a screen to prevent animal life from getting injured in the turbine and is designed to span the entire length of a dam. Moreover, the Williams cross flow turbine exhibits similarities to both a waterwheel and a cross flow turbine. The water enters the turbine at a slight angle after topping the dam but then exits at a height close to the center of the turbine, like a waterwheel. However, the water crosses through the center of the turbine allowing for two phases of energy extraction, like a traditional cross flow turbine as opposed to just one phase as in a waterwheel.

Physical tests on the WCFT were conducted by Sritharan at Central State University to develop a comprehensive testing rig (Sritharan, 2013). The work varied the arm blade attachment mechanisms, the number of blades, the operating head conditions, the load conditions, and the submerged conditions of the turbine. First, the blade attachment and number of blades were altered until an optimal number was arrived at. Next, tests were conducted to measure the power production of the WCFT under differing load conditions using a dynamometer and belt tension running to a generator. The work stated that the efficiency of the WCFT was roughly 80%, although it was noted that due to the fluctuations in the manometer readings flow equations failed to give an accurate result of the flow through the turbine. Moreover, the dynamometer used in determining the power production failed to properly record belt tension going to the generator due to water on the belt. The physical tests at Central State University served to prove the validity of the WCFT from an empirical standpoint, but it also showed that further experiments needed to be performed.

Scherping expanded on the physical testing conducted by Sritharan (Scherping, 2019). This research categorized physical tests into two main components. The first portion of the research was in the physical ability to test the turbine, such as the alignment of the belt driven gear system, how the data was recorded, and how flow traveling through the turbine was directed. This portion of the research improved the fidelity of measurements. Through the implementation of a flow screen, a larger more measurable amount of water was forced through the turbine. By improving the fastening of the belt which connected the WCFT to the generator, which showed the power output through lightbulbs, allowed test power production to be more accurately measured. Lastly, by shifting the WCFT blades over, the clearance between the wall and blades was increased, thus allowing numerous tests to be run without the hindrance of the wall. The second portion of the research focused on testing the flow through the turbine when a debris screen was in place as well as varying the shape of the blades in the WCFT. The effects of these alterations were shown through the development of qualitative power curves. The power curves showed that under the tested conditions of varying flow rates, the turbine blade shape had little effect on the overall power output in all cases. The tests conducted using the flow screens showed that the power output at considerably lower flow rates of 4.2 Liters per second yielded nearly the same results as the 10.19 Liters per second flow rate with undirected flow. Overall, this research showed that potential modifications to the testing rig laid out by Sritharan could lead to improvements in the quality of results produced. Moreover, accurately measurable flow through a turbine would improve tests.

A numerical study employing computational fluid dynamics was conducted by Malkus at Ohio State University (Malkus, 2019). This research utilized numerical simulations relying on Reynolds Numbers Navier Stokes Equations using a Volume of Flow method to model the two phases of flow through the WCFT to determine power production and efficiencies. The research showed the turbine as a two-dimensional model and utilized the flow over the Ogee shape weir to produce power curves. Through varying the shape and number of the blades, along with flow rates, power curves were produced which gave valuable insight into the possibility of further design alterations. Ultimately the research showed that Ossberger blades at a blade angle of 49 degrees produced the most power. Furthermore, the research showed an inefficiency in the WCFT flow inlets. The research showed that by altering the flow inlet bringing water into the turbine as it passed over the weir could greatly improve the efficiency of the turbine. Due to time constraints, this avenue was left to be researched further by other experimenters. Moreover, the tests were never validated physically, only theoretically.

Further computational fluid dynamics research was conducted by Clark which built off of the research performed by Malkus (Clark, 2020). The research conducted by Clark utilized ANSYS software and the Volume of Flow method to analyze the WCFT. This began with first considering various inlet designs. Three different inlet designs were considered, the first two, when tested in ANSYS, produced efficiencies of no more than 60%. However, the third inlet design provided an efficiency of 78%. Through the tests conducted, various flow rates were tested in the ANSYS software. This research pointed out that additional efficiencies could be gained by altering the height of the turbine in the water and by altering the blade outflow distance. Furthermore, the research showed that utilizing the third inlet design allowed for 180 degrees of rotation to produce power from the WCFT instead of the 100 degrees of rotation previously shown. Despite the success of these numerical tests, adequate testing facilities are not present to validate these results physically.

1.3 Small Scale Flume Testing

The best way to test turbines in a controlled indoor environment is using a flume. The Ohio State University does have a flume that is part of the Civil Engineering Department, but it is only modestly utilized, as a small section of students take a Hydrology course each year.

Research conducted by Erb took inventory and created a manual for the teaching flume at The Ohio State University (Erb, 2020). The work outlined specific instructions for the use of the flume including, flow rate measurement as well as each component that alters the flow in the flume. Moreover, the research conducted expanded the teaching capabilities of the flume by implementing visual aids to demonstrate vortex shedding. These contributions to the flume made it possible for other researchers to easily run the flume, thus expanding the number of experiments that could be run.

Conover further evaluated the capabilities of the Ohio State flume by employing pitot tube measurements to characterize the boundary layer profile of the flow within the flume (Conover, 2021). Various forms of measurement of flow rate were thus compared: pitot tube, venturi meter as well as a V-notch weir. The accuracy of each device was established. The results showed good agreement between the pitot tube measurements and the venturi meter. Following the flow rate measurement evaluation, Conover focused on evaluating a siphonic hydropower design tool designed for Rickly Hydro (Cook, 2017). For this validation exercise, a weir and scaled siphonic system was built and tested in the flume. The validation of the design tool was successful with the scaled experiments providing good agreement. Ultimately, the research showed errors in the flow rate measurement devices in the flume manual as well as the venturi meter.

Research conducted by Senior at the University of South Hampton, studied the power production and torque of a Rotary Hydraulic Pressure Machine (Senior, Weimann, and Muller). This research utilized physical studies to determine the efficiency of these devices. The process utilized in this research to measure the power and torque was a Prony brake. A Prony brake utilized a friction wheel, counterweight, and spring system to decelerate a rotating shaft through friction applied at a known force.

The bodies of research cited in Section 1.2 and Section 1.3 offered inspiration for future comprehensive testing rigs (Sritharan,2013) and improvements to flow direction through turbines (Scherping, 2019). They suggested measurement techniques for measurement (Erb, 2019) and the limits of current flow measurement in an experimental flume environment (Connover, 2021). In addition, the research considered aspects of a prospective testing rig that should be able to be altered easily, such as the type and number of blades (Malkus, 2019) as well as the inlet and direction of rotation for the turbine (Clark, 2020).

1.4 Overview of Thesis

The main goal of this project was to develop a testing rig that would improve the fidelity of experiments conducted to progress research on low head hydro turbines both at Ohio State

University and abroad. The testing rig would benefit from numerous adjustments that would allow the researcher to test multiple variables quickly and with little additional work. The testing rig that was considered had an adjustable height such that the head coming over the weir could be altered as necessary. The testing rig had to include a commonly used weir. Furthermore, the testing rig needed to be collapsible and have an adjustable inlet and outlet component.

Research started by following the Product design procedure outlined by Ulrich and Eppinger in Product Design and Development. The process utilized the development of a Problem, conducting research into existing methods, initial design considerations, concept screening, further iterations, prototyping, and testing (Ulrich & Eppinger, 2016). Ultimately, this research focused on the stages of the design process prior to physical prototyping and testing but laid the groundwork for future research to be conducted to prototype and test the physical testing rig. Despite the previous tests conducted, it was determined that more accurate testing facilities were required to improve the fidelity of experiments and empirical data. The research conducted and outlined in this thesis show a potential design solution for a testing rig to achieve these higher accuracy results.

The following chapters in this thesis break down the steps taken to reach the final testing rig. Chapter 2 will discuss the initial design considerations and specifications needed. Chapter 3 will show the development of the modeling after extensive screening of designs and how first design concepts were achieved. Chapter 4 will discuss the optimization of the design through numerous iterations and how that determined the materials required for constitution. Chapter 5 will discuss the sourcing of materials, the actual construction, and assembly of the testing rig. Lastly, Chapter 6 will serve as a conclusion to this thesis.

Chapter 2

Initial Design Stages

Chapter 2 will discuss the utilization of the product design procedure to consider the requirements of the testing rig. Then the chapter will show some initial designs that were considered to achieve the needs deemed most important.

2.1 Consumer Needs/ Benchmarks/Target Specs

Framing the project from a product design standpoint allowed for a methodical approach to developing the testing rig. The initial step, following motivation, was to outline all the consumer needs or objectives that were required to be achieved. Based on the research conducted by Ohio State researchers' numerous necessities were presented. Clark's research conducted in CFD required that the turbine being tested have an adjustable height, an adjustable inlet flow angle, adjustable direction of rotation, and a stiff backing both behind the turbine and in front of the turbine. Malkus's research concluded the importance in testing different variables of the turbine itself, namely the type of blades, numbers of blades, and blade shapes through CFD. Scherping's and Srithran's research, while experimental, raised concerns over the ability to direct flow through the turbine, how to accurately measure this flow, as well as how to minimize the turbidity of the water and splashing of water onto test equipment. Lastly, fellow researchers Anna Lebron, who was working in conjunction, investigated techniques for measuring the torque and speed of the turbines, which had to be easily connectible to the proposed rig.

Following the design procedure, the next step was to outline constraints. The main size constraint of the testing rig was that it had to fit within the flume at The Ohio State University. The roughly 30-foot length of the flume was not a concern, but the 12-inch-wide channel with

15.5-inch-high walls limited the size of the rig. The area above and below the flume were relatively open making neither of these areas of great concern. Due to budget constraints, the overall cost of the project was limited to a maximum of $1,000. Emphasis was placed on cost cutting measures both throughout the design and optimization portions of this project.

With the design parameters and constraints in place it was clear that the testing rig could be divided into numerous design modules. The diversion had to: allow for an entire measured flow of water to flow through the turbine, have walls no taller than 15 inches high, have a width no narrower than 8 inches, and be easily removed by one person. The turbine testing equipment had to: be out of reach of water, be efficient and effective at measuring the torque and power of the turbine being tested, allow for ease of access testing equipment, and connect seamlessly with the rest of the testing rig. The weir had to: simulate real test conditions of non-powered dams, be no greater than 12 inches tall, and be a common weir shape. The turbine testing had to: allow for different width turbines, allow for the test turbine to have a maximum diameter of 6 inches, allow for a screen to be attached, allow for the turbine to be raised and lowered in the flume, and allow for the turbine to flow in different directions. Lastly the flow direction of the turbine had to: have a backflow inhibitor to match the size of the turbine, have an inlet flow that could be varied to different angles guiding water into the turbine, have a flow diverter after the turbine, and have the flow equipment be adjustable to the height of the turbine. Along with these aspects, cost was to be kept with a minimum and it was ideal that the experimenter be able to see what was occurring during the test.

2.2 Preliminary Designs

Based on the concerns posed by previous researchers, the following requirements were established. Based on Clark's research, the testing rig would need a way to easily raise and lower the turbine being tested while guaranteeing a watertight seal. In addition, a way to adjust the inlet flow would need to be developed that would be accurate in letting the correct amount of water into the turbine. The testing rig would need to include a way to limit the backflow which would serve as a block and would accompany tests done on the turbine. Lastly, the turbine would need to be able to be easily removed and reversed.

Upon Malkus's concerns, the testing rig had to allow for the easy removal and installation of the turbine. To help alleviate the cost of the testing rig, it was further determined that it would be advantageous to allow for the rig to accept different models of turbines besides just the Williams Cross Flow Turbine. Scherping's and Sritharan's research concerns could best be achieved through the development of a diversion that ran the length of the channel. Lastly, Lebron's research of measurement equipment indicated the need for a dry area to connect a Prony brake system employing pulleys and other interchangeable elements.

The diversion was the first major component that needed to be considered. Initially three main concepts for the diversion were considered. Figure 2.1,2.2, and 2.3 below shows the first three sketches associated with the diversions. At this initial stage, the functionality of the design and general principle was considered more than the actual specific workings or material specifications. While crude to begin with, these sketches provided the much-needed visual aides to begin modeling the testing rig. The first diversion design was a simple three-piece diversion including a main retaining wall, behind which the equipment for the Prony brake connection was stored, and the two contraction and expansion walls. This design relied on a one-sided diversion where the turbine would hang in the water. Figure 2.1 below shows this design.

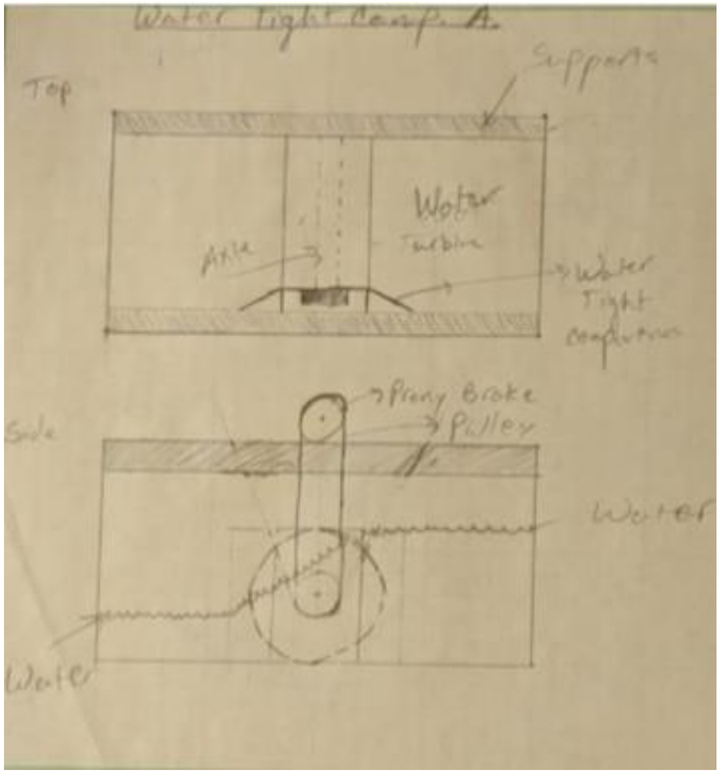

Figure 2.1: Water Diversion 1 Sketch

The second diversion design, Figure 2.2, utilized adjustable clamps to change the angle of the expansion and contraction walls. This design didn't rely on anchoring to the floor but rather relied on friction holding clamps.

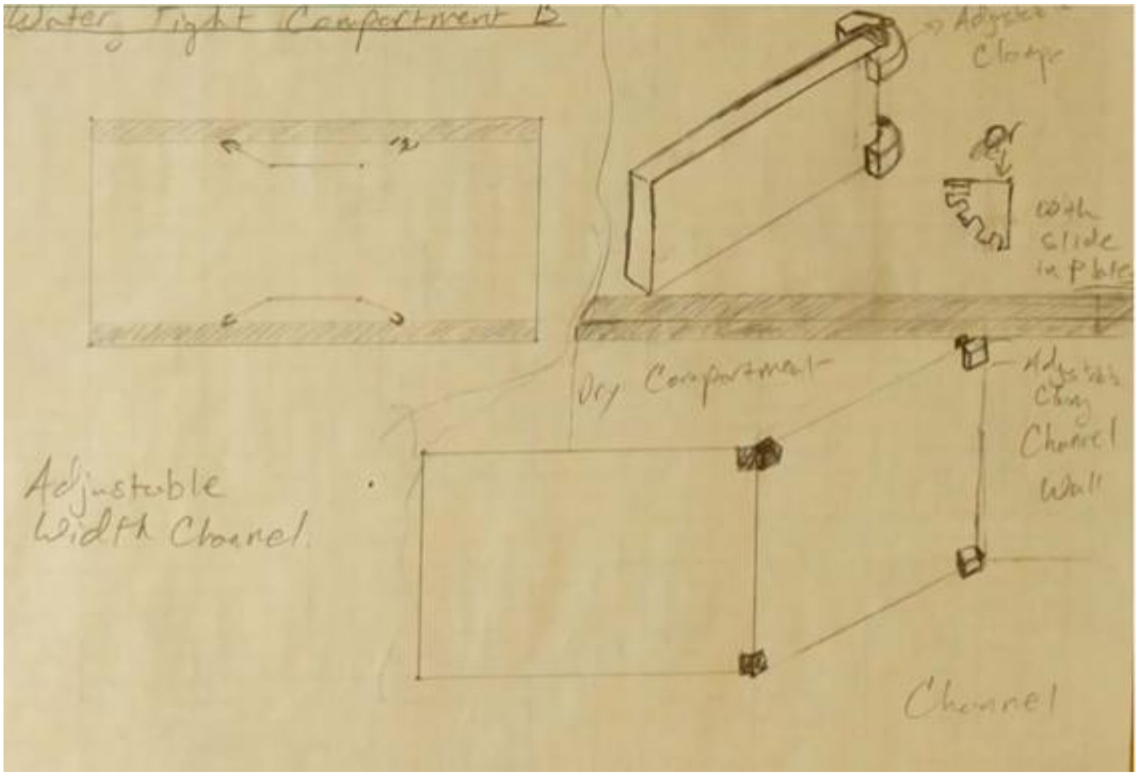

Figure 2.2: Water Diversion 2 Sketch

The third diversion design utilized a porous grid to which the retaining, contraction, and expansion walls were held in place with pins. The pins would click into place allowing the walls to form watertight seals for the equipment. Like the adjustable clamp design, this grid and pin design utilized two separate divisions to form the central channel. This is shown in Figure 2.3 below.

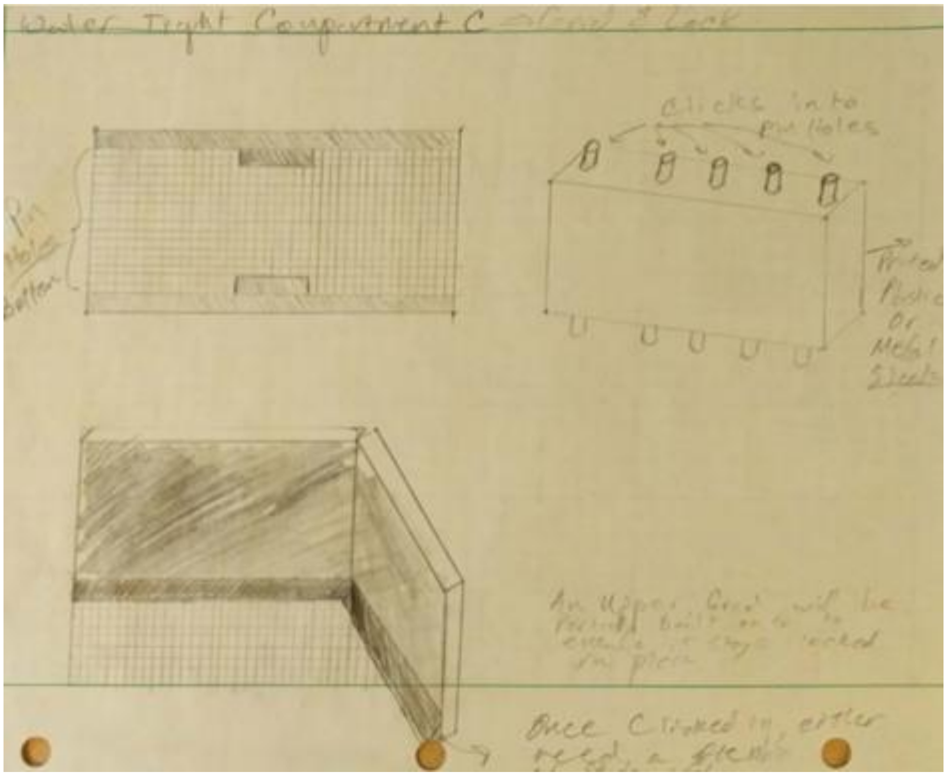

Figure 2.3: Water Diversion 3 Sketch

The next major area of the design consideration was how to raise and lower the turbine. 8 designs were considered. The first design utilized two trailer jacks to raise and lower two separate platforms at the same rate which held the turbine between. The trailer jacks relied on thin lead screws that could be motorized to expedite the lifting process. Figure 2.4 below shows this design.

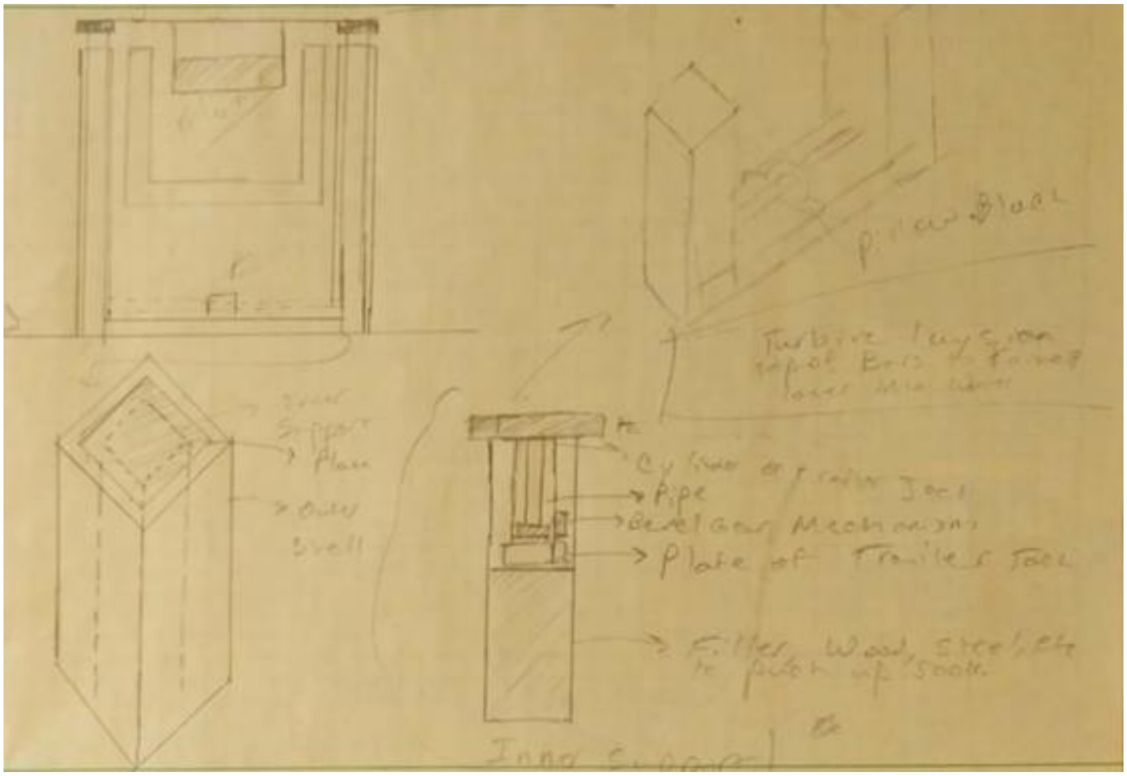

Figure 2.4: Trailer Jack Raise Design

The second design utilized a winch connected to a pulley above the flume. The winch would be connected directly to the flume itself. By rotating a handle, the turbine would raise or lower. This however, limited the lateral movement of the turbine down the length of the weir. Figure 2.5 below shows this design.

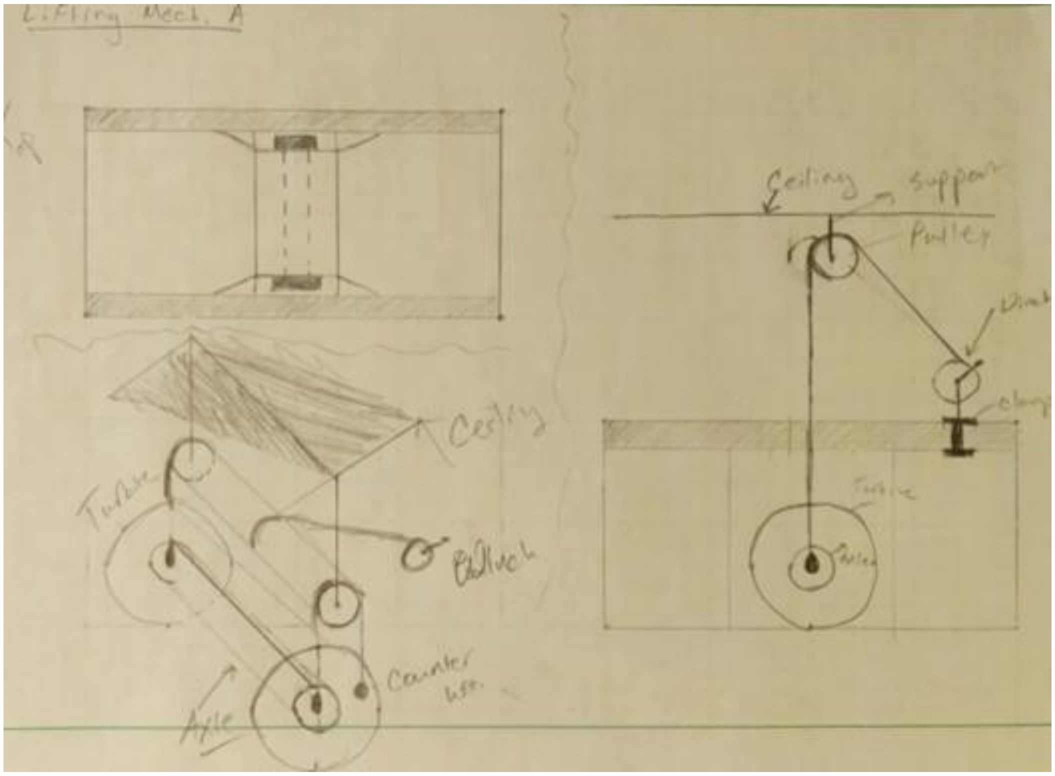

Figure 2.5: Winch Lifting Design

The third design utilizes two lead screws and a crank to move the position of the turbine laterally down the length of the flume as well as up and down into the water. The lead screws would work like a Bridgeport end mill. This required a large floor bound apparatus to guarantee stability. Figure 2.6 below shows this design.

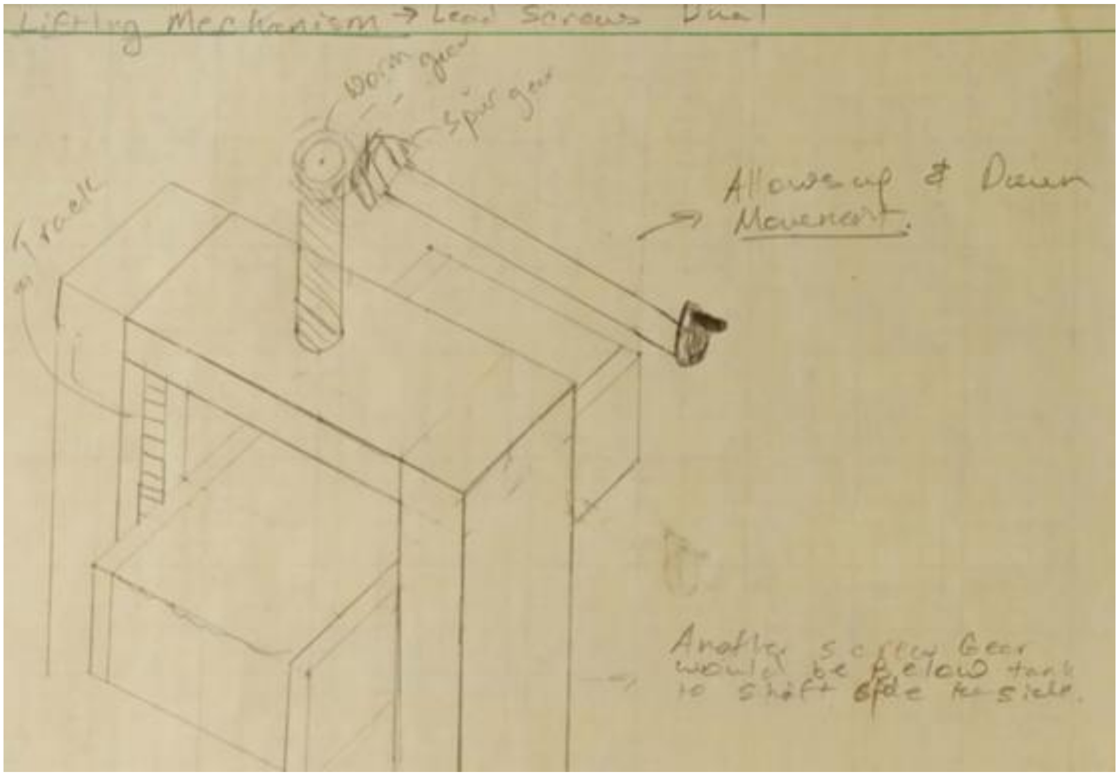

Figure 2.6: Bridgeport Design

The fourth design utilized a notched raise and lower interface. The floor bound legs would have a series of holes drilled in them that would allow the position of the turbine to be chosen discreetly. The experimenter would compress a scissor type spring mechanism that would close the pins and allow free movement between the supports. The experimenter would then release the spring locking the new position in place. This would have forced the experimenter to physically lift and hold the turbine for the duration of the position change. Figure 2.7 below shows this design.

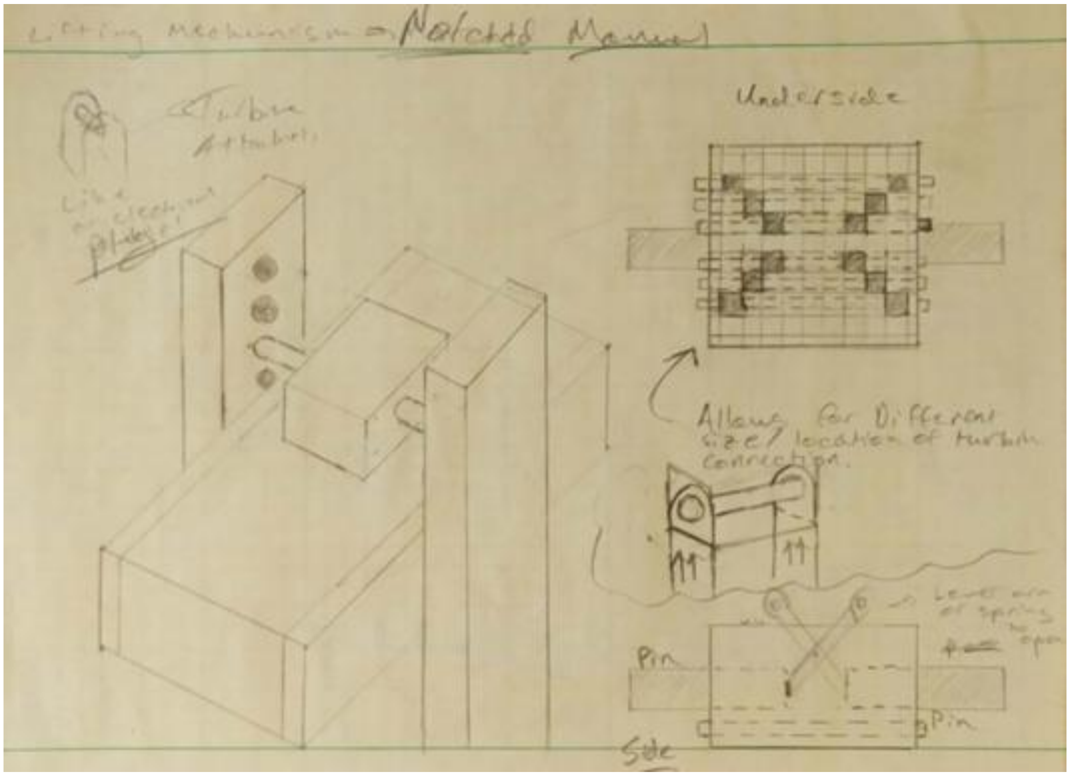

Figure 2.7: Pin and Scissor Raise Design

The fifth design utilized two linear motion motors with gearing to act as a rack and pinion to lift the turbine up and down and side to side. The positioning of this model was precise, but the equipment was expensive. Moreover, the motors needed to run along a geared interface with floor length supports. Figure 2.8 below shows this design.

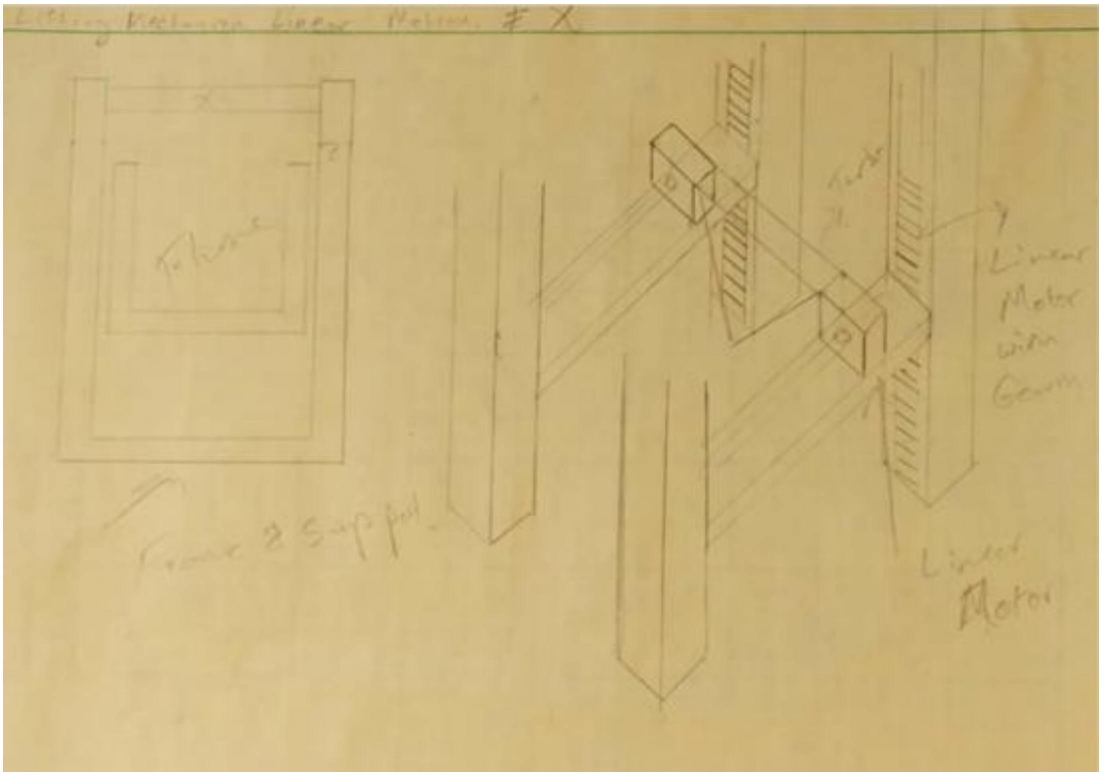

Figure 2.8: Linear Motor Raise Design

The sixth design utilized a roller chain mechanism with large support to raise and lower the turbine held rigidly in place like a guillotine blade. This design was manually driven and the roller chain and winch made for easier movement of the turbine, but limited the lateral or side to side movement of the turbine in the weir. Figure 2.9 below shows the design.

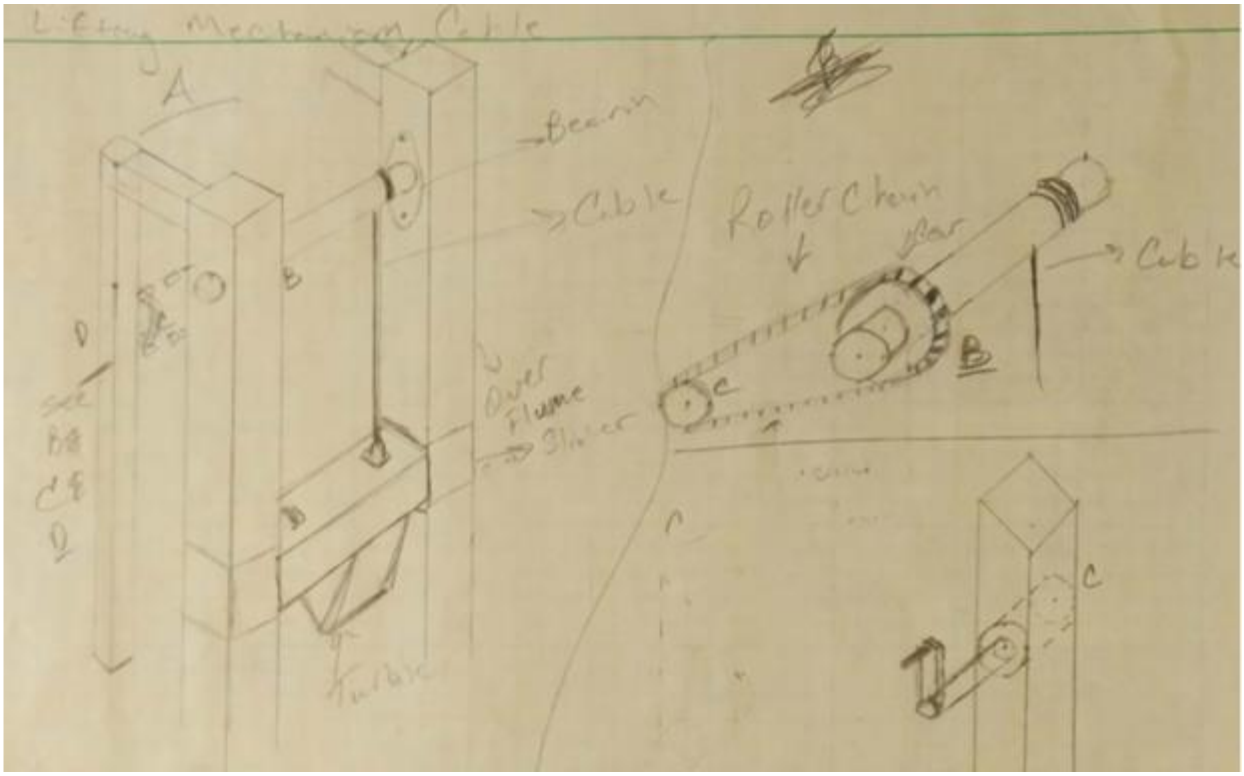

Figure 2.9: Guillotine Roller Chain Raise Design

The seventh design utilized two cars with scissor actuated lifting mechanisms that would run along the floor. The benefit of this design was the applicability of the carts for storage and easy collapsibility next to the flume. The carts could have their path limited by pieces of wood on the floor or metal tracks. However, the raising and lowering capabilities of these carts limited the precision. Figure 2.10 below shows this design.

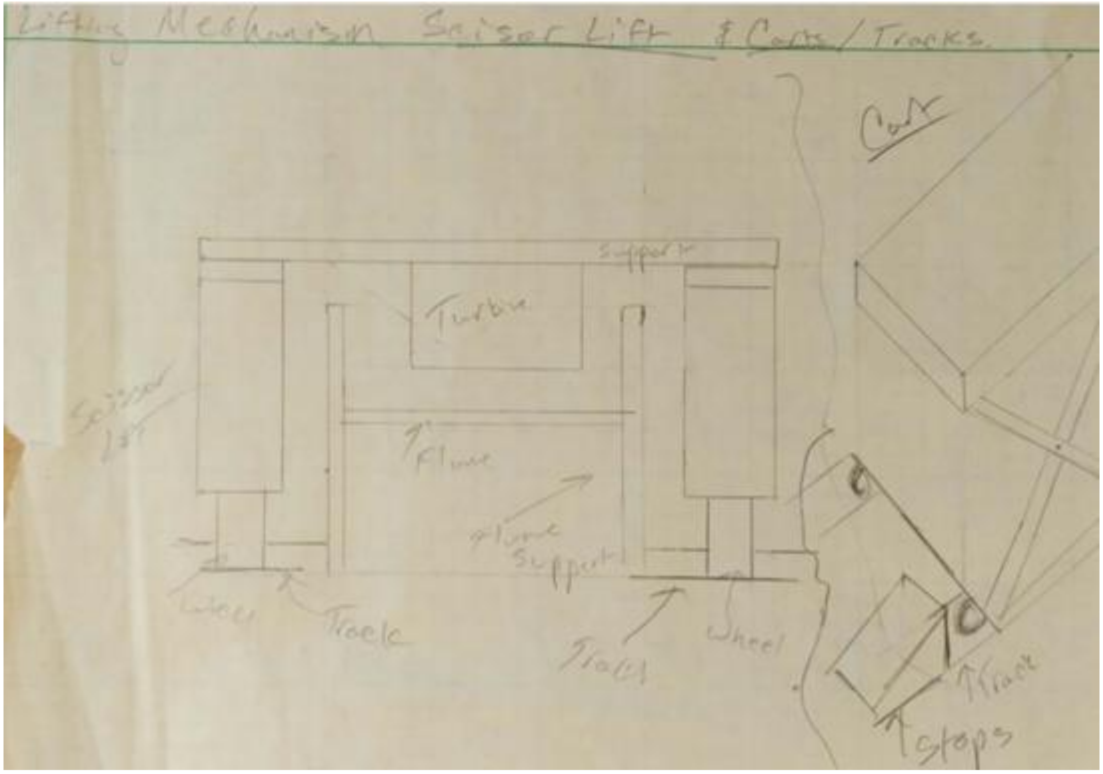

Figure 2.10: Scissor Lift Cart Raise Design

The eighth design utilized a chain hoist mounted to the I beam in the ceiling above the flume. The design would allow for larger objects to be raised and lowered but limited the 3 possible directions of movement for the turbine to only 2: down the length of the flume and vertically. Although sturdy, this design was limiting from a cost perspective. Figure 2.11 below shows this design.

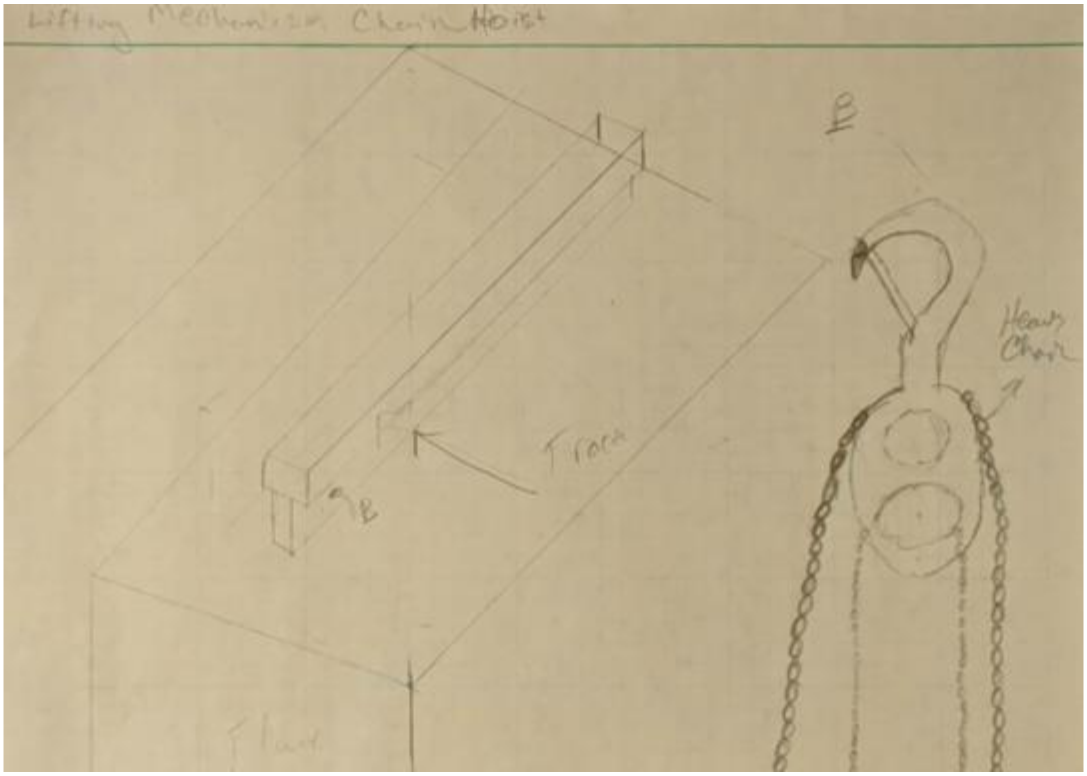

Figure 2.11: Chained Hoist Raise Design

Directly related to the raising and lowering of the turbine was the consideration of the interface which would hold the turbine in place. There were two main designs as shown in the Figures related to the early sketches above. Not explicitly shown was bolting the turbine in place to a plate which would allow for rigidity in movement. Each turbine design would either be bolted to the plate attached to the movement mechanism or the size of the turbine would be limited to the predrilled holes. The other design considered in the early stages was shown in Figure 2.7 above in the same drawing as the Pinnable raise and lowering system. This design allowed for the turbine of choice to be plugged into one of several different locations with a dual prong connection with a hole running through the center like a wall outlet electrical plug. The plug holes would be drilled into the raise and lowering plate and a pin would hold the turbine in place by running through the holes in the prongs.

The movement of the turbine, either side to side in the diversion or up and down the length of the flume, was considered in addition to the vertical movement. Not many differing ideas were put forth to move the turbine laterally though as it was assumed that the turbine would remain in the same position horizontally in the channel between runs, and that merely pushing the holding mechanism down the length of the channel would be easily achieved if the mechanism was on wheels. Like the diversions, there were three main designs for the weir or dam. The first was to create a series of weir shapes in rigid forms out of wood, aluminum, or some form of plastic. The benefit of this was that the weir could be used virtually unlimited times before it broke down. The downside was that different weir shapes would have to be created as well as different heights created if variability of the weir wanted to be tested, which would increase the cost of this method quickly. Figure 2.12 below shows this design.

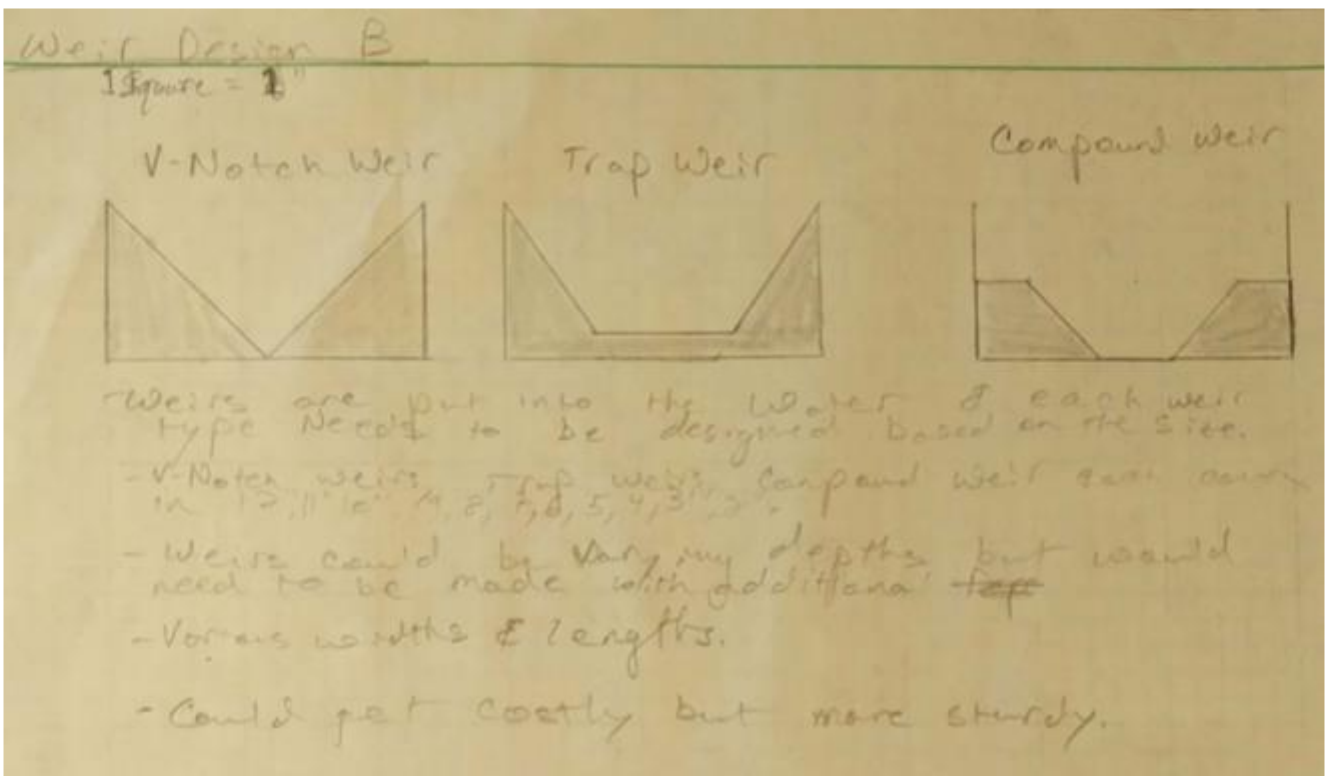

Figure 2.12: Weir Shape Design

The second weir design was a more adjustable weir that utilized LEGO type bricks to allow for the weir height to be easily adjusted. The bricks would slip together creating an endless supply of weir sizes and shapes. The modularity of the design came at the cost of long assembly times, and increased machining to prepare the equipment. Moreover, this design would prove unproductive if only one main weir design needed to be tested. Figure 2.13 below shows this weir design.

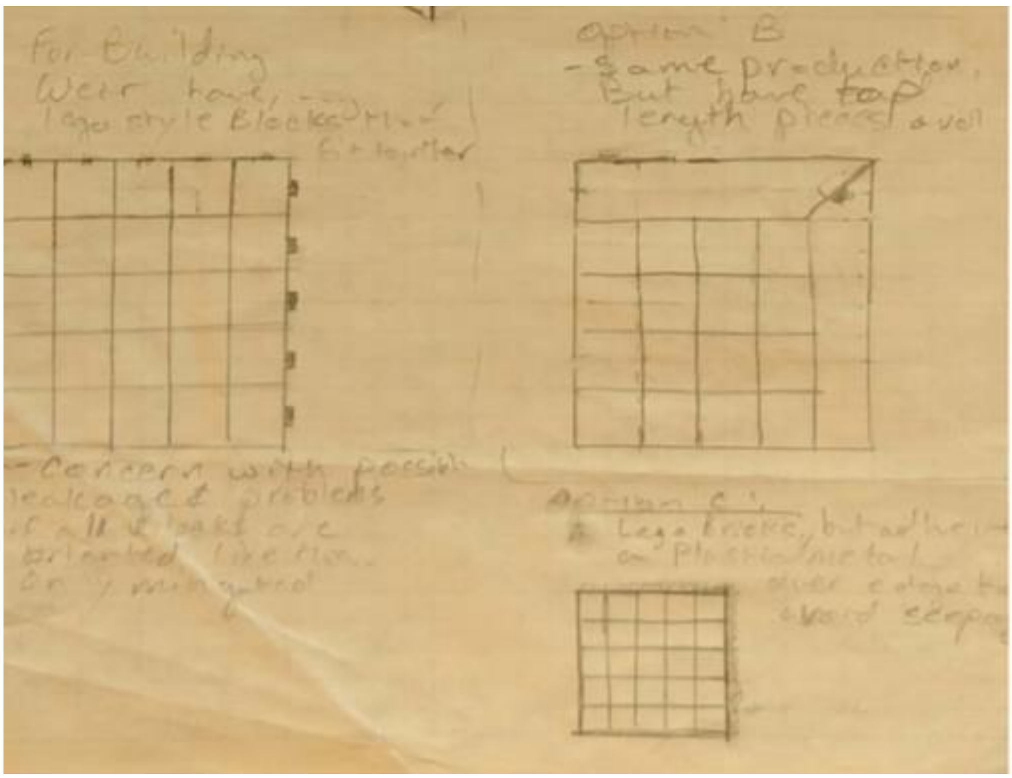

Figure 2.13: Lego Weir Shape Design

The third weir design branched off the work of Ohio State Student Nan Hu who utilized an origami weir made of ArmaForm (by armacell) structural foam that would shift as water passed over it. The design chosen used the same origami bricks of foam but rigidly held in place due to the width of the weir. Like the LEGO weir design above, this design required the manufacturer to create a series of shapes beforehand that the experimenter would construct as desired. The material afforded the manufacturer with lower costs than the LEGO style weir, but once again the design seemed impractical if the weir was not intended to change. Figure 2.14 below shows the weir design.

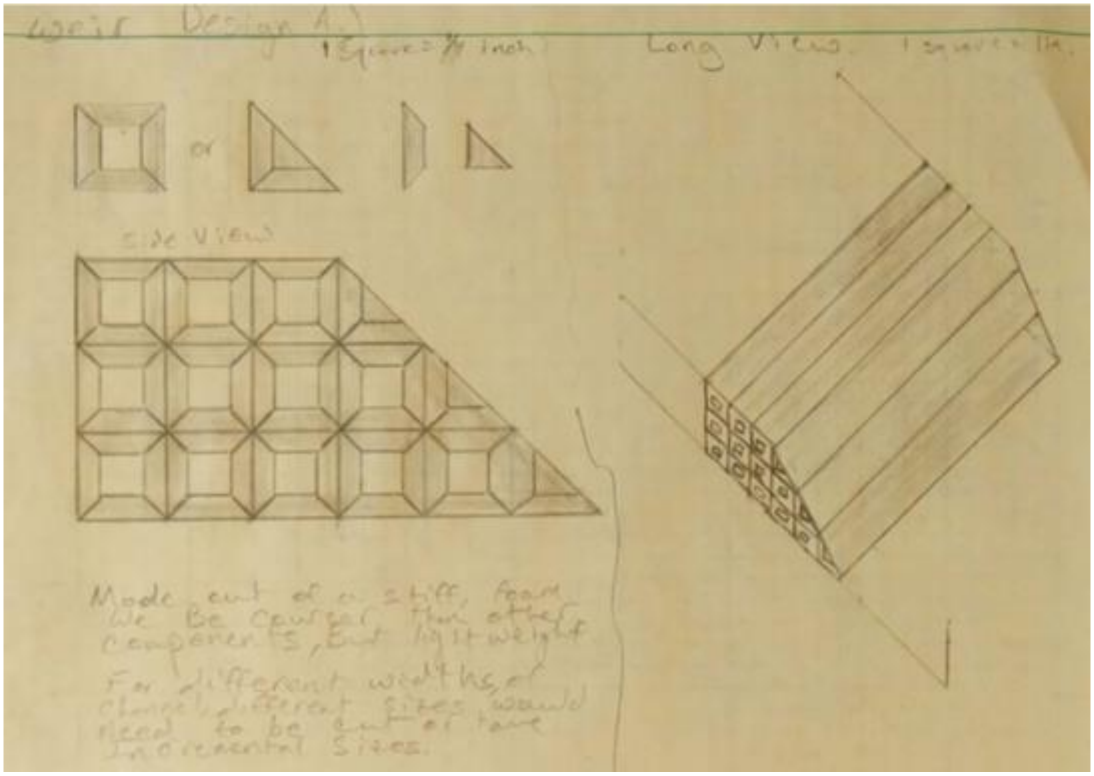

Figure 2.14: Foam Weir Blocks Design

Not shown in the early sketches were inflows, outflows, or screen holding mechanisms. These were not considered the major components necessary to build at the initial stages and the general idea was that these components would just attach directly to the weir, diversion, holding, or raising mechanism once one was decided on.

From each of the different sections of possible design modifications that tradeoffs were necessary. Some designs offered increased rigidity at the expense of difficult maneuverability. Others offered precise locationing but at high cost. Still more offered increased modularity but with more machining and assembly. Following the initial design sketching process, each major area of design was considered, and the important attributes were reiterated.

2.3 Conceptual Screening

In traditional product design and development often a numerical concept screening and scoring is utilized to determine a quantifiable best option with regards to numerous factors such as assembly time, variability, cost, machining time, etc. Due to the inter-connection of so many different parts, some of which were unclear at the time of initial sketches, the decision was made that further models be created using SolidWorks. These models would be created emphasizing the most desired characteristics and minimizing the least desirable characteristics while building off the sketched designs which proved to be the most promising. Furthermore, to make up for the lack of a formal concept screening and scoring process, a more diligent and extensive optimization step would occur to minimize costs following the freezing of the design. This optimization process is shown in Chapter 4 of this thesis.

Following the initial design sketches some broad modifications were considered. Floor length devices were discarded. This decision would reduce the cost of the testing rig and would allow for the once cumbersome device to be more easily stored. Any new devices, requiring a solid surface below, would sit on the aluminum sill of the flume. Next, it was determined that the raising and lowering of the turbine was an essential feature that had to be easy for an average experimenter to do, but that it was not necessary for it to be done during test runs. Therefore, it was not a concern that water sensitive devices would be damaged during a testing change as the water would not be flowing in the flume. Furthermore, collapsibility of; diversions, raising/lowering, and holding mechanisms was deemed crucial to provide easier storage, movement, and transport. Moreover, designs that were specific to the preexisting testing site at

Ohio State were jettisoned in favor of designs that could easily be adapted to flumes in other locations in an attempt to provide more testing locations with a low-cost rig that would improve the validity of said test site.

In addition to the broad design changes considered, more specific design changes were outlined. For the diversion, it was determined that the use of friction holding clamps, or a pin interlocking system would not be necessary, as the diversion itself would not change enough between tests to condone such a modular system where the width of the channel itself or the angle of contraction/expansion would be altered. For the raising and lowering systems, the major portion of the decision making lay in the consideration between discrete and continuous designs. As the raising and lowering system directly connected to the holding mechanism, the designs had to be modeled together to ensure that seamless interactions could occur. Every design had to be considered on a discrete or continuous basis along with how it inter-connected with the other testing rig components. For the holding mechanism, it was determined that the parts should be modeled using a Williams Cross Flow Turbine that could be changed easily to accommodate different style turbines.

Chapter 3

Test Rig 3-Dimensional Modeling

Chapter 3 discusses the development of each major component of the testing rig that was considered. Save for a few instances, all models in this chapter are the first design choices for each of the components of the testing rig prior to any optimizations of size and material. For brevity, iterations of the design process are included in Appendices C- F: Model Iterations.

3.1 Flume

To begin the refined modeling and idea generation, measurements of the flume in Hitchcock Hall were taken. These measurements were compared against the user manual for the flume. With accurate sizing, a 3-D model was created in SolidWorks. Figure 3.1below shows the modeled flume space. For the purposes of this design project, the flume size, spacing of holes and relative distance to the ends of the opening were critical. Material was chosen to be as close as possible. However, other aspects of the flume were not considered vital to the development of the testing rig in the modeling stage, therefore venturi meters as well as manometers are not included in this or subsequent models and diagrams.

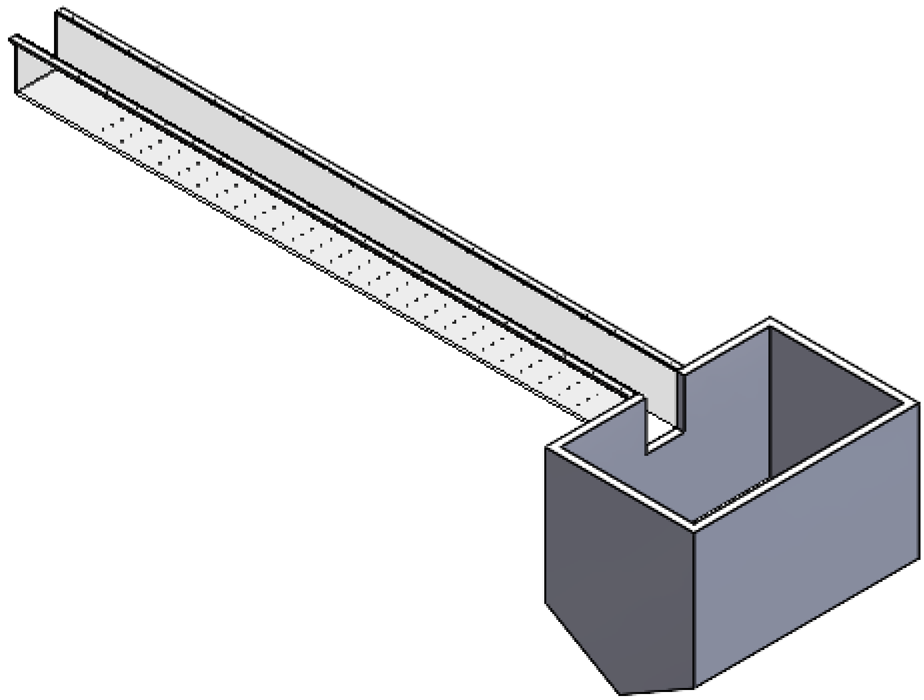

Figure 3.1: Model of Flume Assembly

With the flume accurately modeled, iterations in the design and modeling of each component in the testing rig began. Figure 3.2 below shows the completed first design testing rig in the flume.

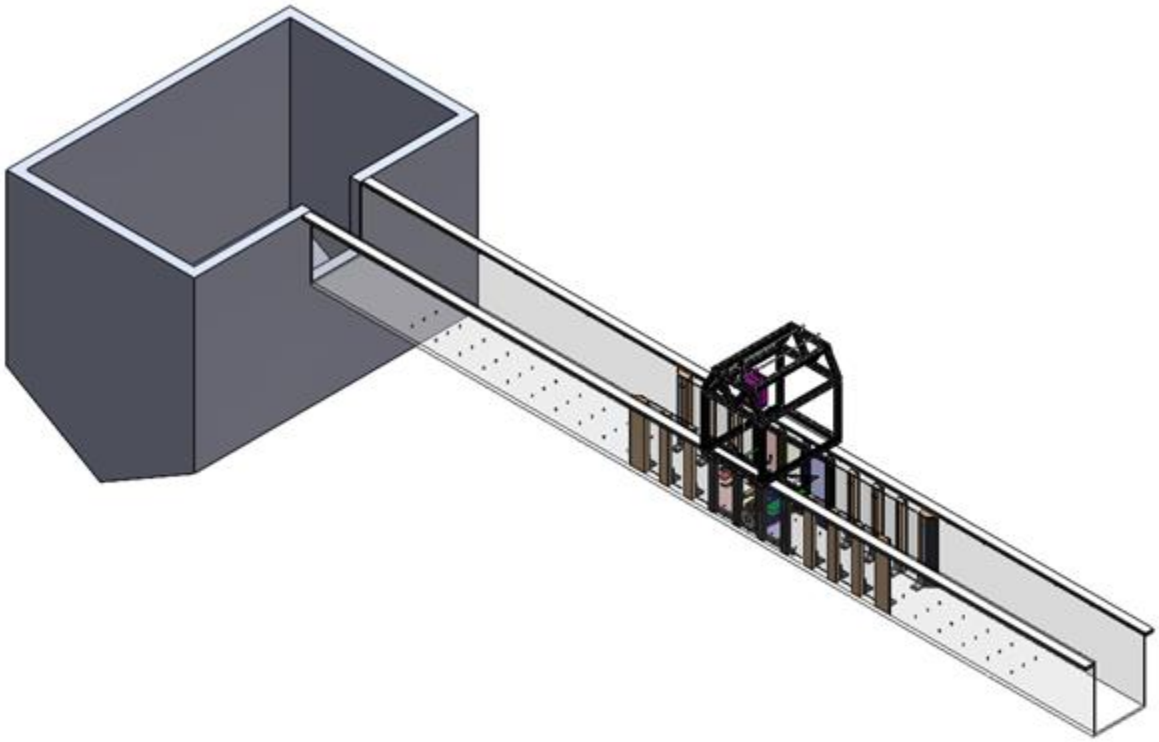

Figure 3.2: First Design Testing Rig and Flume Assembly

3.2 Diversion

The first major component considered for the testing rig to accurately measure and improve testing capabilities was the diversion. Initially a solid diversion was considered. The initial diversion model is shown below in Figure 3.3.

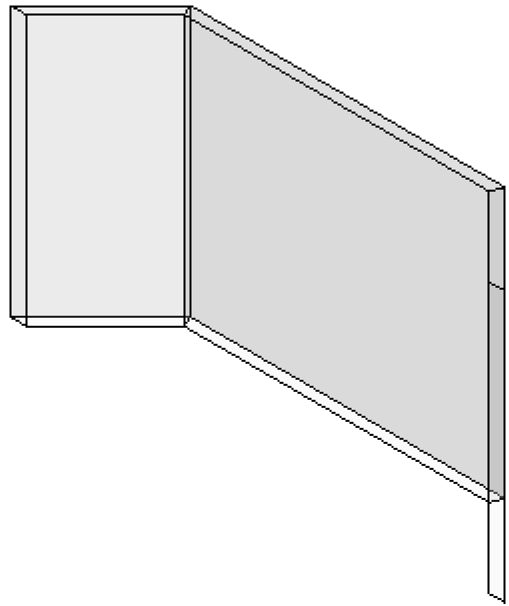

Figure 3.3: Initial Diversion Design

This diversion utilized three pieces of plexiglass held together with caulk to form a 24-inch-long contraction and expansion. This design assumed that the testing turbine holding equipment would be held within the walls of the diverted flow. This design was later discarded for three main reasons. First, the solid formation of the diversion would be difficult to lift in and out of the flume. Second, it was determined that the diversion should also hold the turbine testing equipment within the cavity formed between the flume wall and the diversion wall to maximize the flow over the turbine. Third, with the desire to have the turbine held in the diversion, the solid three-piece plexiglass diversion limited the position of the turbine within the diversion unless entire new middle sections were machined for each turbine positioning.

After a series of iterations, shown in chronological order in Appendix C: Diversion Modeling Iterations, the following diversion was decided upon. Figure 3.4 below is the first design needed for the diversion.

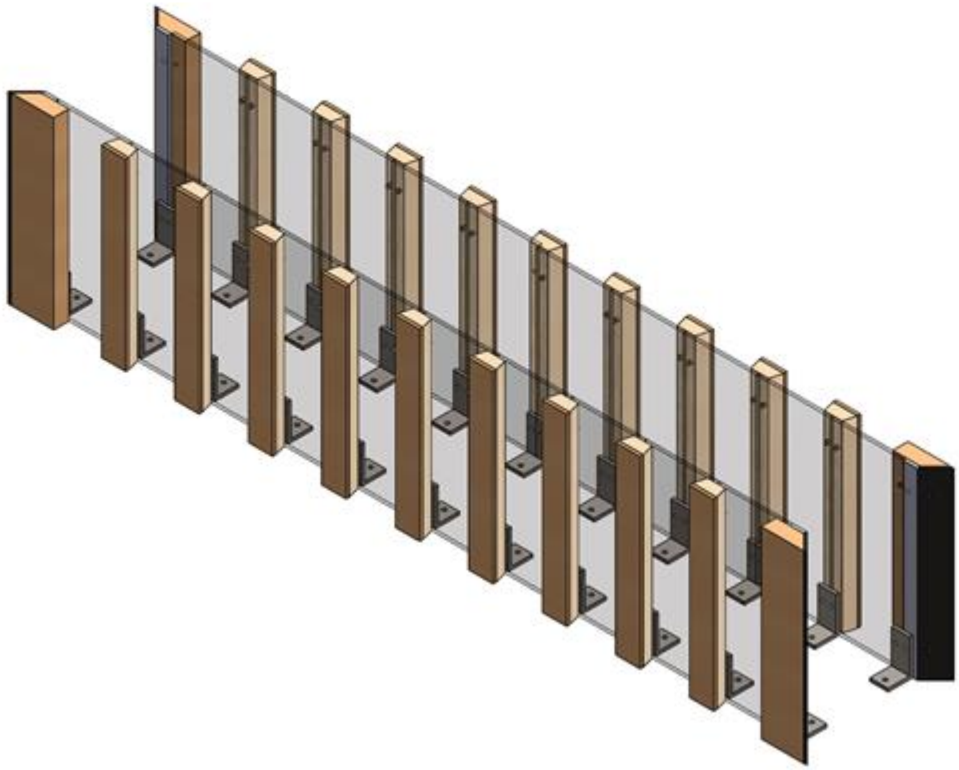

Figure 3.4: First Design Diversion Only

The first diversion design had many alterations compared to the original design. First, the length of the diversion was changed from 24 inches to 48 inches. The length was extended to give the flow time to settle. Furthermore, the diversion shown here is dual sided instead of a single sided diversion to distribute the force more properly from the water and turbine. Lastly, this diversion design allows for the turbine to be housed within the 9-inch channel width present within the diversion within the flume.

Each part of the diversion was deliberately planned. Initially, no support was considered for the diversion. As iterations occurred, it became clear that the holes along the bottom of the flume would prove beneficial for anchoring the diversion in place. The grey L brackets shown in Figure 3.4 above are specially designed L brackets made from an aluminum extrusion with 3-inch legs that are 0.25 inches thick. These L brackets will have three clearance holes for ¼-20 bolts drilled in them: one along the 2-inch leg that will allow for the bracket to be secured to the flume channel floor, the other two will allow for the bolts to hold the buttresses diversion walls in place. The buttresses shown here are made from solid wood adhered to plywood to distribute the load of the water pushing on the diversion walls into the thick flume walls. The tapered shape of buttresses was designed to help direct the force and increase the viewing capability of the experimenters. Earlier designs used a simple thin metal support, but this was a design prone to leaks and the metal supports seemed to flimsily hold the acrylic sheets in place.

The wall sections are made from 6 inch wide, 15 inch high, 0.25-inch-thick acrylic sheets. The earlier designs utilized 12-inch-high walls, but 15-inch walls were decided on to allow for more water to easily flow over the weir and through the turbine to maximize the head. 6-inch wall sections were chosen to offer a combination of modularity and support. Long wall sections as shown in the 24-inch-long plexiglass diversion were more subject to bending stresses in the middle of the diversion. By shortening each section of acrylic to only 6 inches, the length of the flume could be easily incremented shorter or longer, better supported, and less prone to failure.

Moreover, the 6-inch sections allowed for the turbine casing and therefore positioning of the turbine relative to the contraction and expansion of the diversion to be more easily chosen. 6-inch sections worked as a compromise between excessive bending and modularity as the anchor points in the flume floor are spaced at 6-inch intervals allowing the experimenter to choose exactly where to position the plates. Acrylic was chosen over other materials for its high visibility, ease of workability compared to glass, and low weight to strength ratio compared to glass. 0.25-inch diameter holes were cut into the acrylic 2 inches from the top and 2 inches above the bottom of the plate to allow for the diversion walls to be mounted to the wood buttresses for support and L brackets along the floor of the flume for rigidity.

The corner supports are made of two by four sections cut at 45-degree angles and sanded down to 1.25 inches in thickness to allow for the contraction and expansion to follow a smoother path of entry and exit. Due to fluid flowing directly against the ends of the diversion, the diversion utilized the same buttressed wood techniques as the rest of the diversion to ensure that the pressure was directed into the walls of the flume. Aluminum sheets of 0.25-inch thickness were added to the ends of the flume to act as additional support and to prevent the water from soaking the wood end supports. While the design is assumed to be watertight, it is recommended that additional removable sealant be added along the bottom diversion to prevent water seepage. This could be in the form of a removable duct tape or caulking tape or could be pieces of rubber gasketing that will form a seal when pulled to the floor of the flume.

3.3 Weir

During the development of the weir for the testing rig, numerous weir shapes were considered. While shapes such as the sharp crested and the V-notch have well documented flow patterns, the proclivity of the ogee shaped weir in existing rivers and NPDs made it the obvious choice for testing. Initially a changeable weir shape was considered, however it was determined that a more rigid weir would be beneficial as the first tests conducted with the testing rig were considered to focus only on the most common instances of turbine trials as opposed to pure optimization. The first design considered is shown below in Figure 3.5.

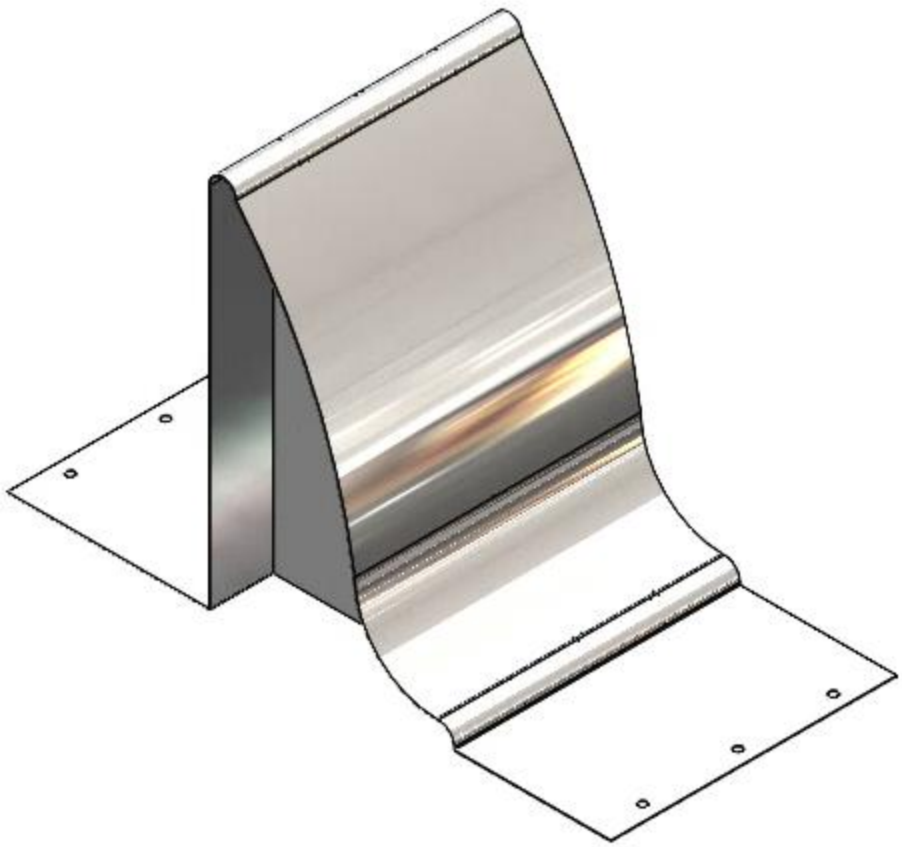

Figure 3.5: First Design Weir and Supports

Figure 3.5 is made from gauge 14 (0.064-inch thickness) aluminum sheeting. To help ensure rigidity, polyurethane 0.25-inch thickness sheets will be cut to match the interior of the weir and they will be adhered into place using an adhesive. The holes along the bottom of the weir allow for the weir to line up directly with anchor holes in the flume. The reduced modularity of the weir component of the testing rig, allowed for much needed structure in the design process. This allowed for higher quality construction of the weir while allowing for different designs to be created in the future to test the effects of different shapes. Aluminum was the optimal material for the weir due to its ease of manufacturing, its low cost, its high strength to weight ratio, and its anticorrosive properties. The plastic supports underneath likewise were chosen for the low cost, high rigidity, and ability to be machined to shape easily.

3.4 Casing

Although the idea of using a modified wall was considered for most of the iterations, it became apparent that a more rigid, easily changeable casing was necessary. A casing similar to the design used at Central State University for the Williams Cross Flow Turbine was considered. Figure 3.6below shows the drawing for this casing used at Central State University.

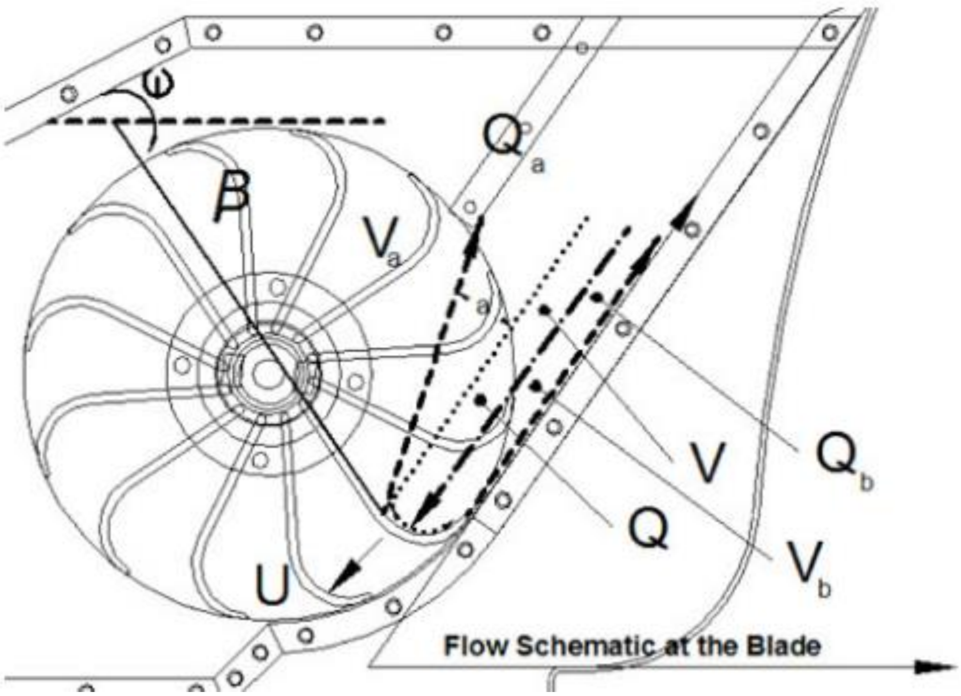

Figure 3.6: Williams Cross Flow Turbine Casing

While the casing at Central State University offered structure for the testing process, it limited the variability of testing. Therefore, a hybrid casing was considered where the casing could be rigidly removed and inserted into the diversion but could be altered as necessary to make adjustments to the testing parameters. After numerous design iterations, Figure 3.7 below shows the first design of the casing.

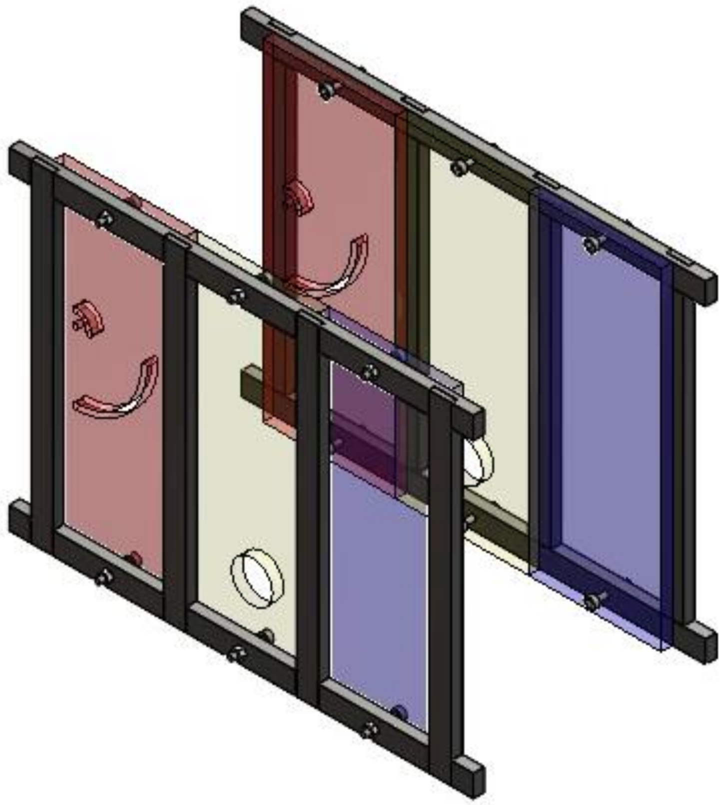

Figure 3.7: First Design Casing Only

The casing above in Figure 3.7consists of a frame, buttresses, and three separate panels. Figure 3.7 above shows the casing with color coded acrylic blocks to show the design more clearly. The frame allows the three panels to be securely attached in one continuous unit thus creating the “casing”. This frame is made of aluminum bars that are 0.5 inches thick along the top and bottom. 0.25-inch-thick aluminum bars sit along lap joints to maintain position and rigidity. Short bolts hold the four lap jointed supports to the upper and lower frame on each side. These bolts are counter sunk to ensure that the buttresses can sit flush against the supports. The buttresses, while smaller than the ones utilized for the actual diversion, perform the same function- they divert the pressure from the water to the walls of the flume. These are made of ¾ inch plywood which sit flush to the wall.

The three panels are the main components of the casing. The first blue panel serves as an observation panel for the researcher. This panel will be constructed of acrylic and allows the researcher to view the experiment more easily. The second, yellow, panel is the panel which will hold the turbine shaft in place. Attached to this central panel will be the 30 mm ball bearing and the lip seal. Attached to this middle panel is the support for the turbine shaft. Again, acrylic was chosen here for its low cost and ease of manufacturing. Pieces of the 0.25-inch-thick acrylic can easily be purchased, and different width holes will be drilled to support various turbine sizes and shapes. The third, red, panel is the outlet flow direction panel. The outflow will be directly attached to this and will allow for angling and adjustment as needed to match the turbine. Due to the stresses experienced, this part of the casing will be constructed of 0.25-inch-thick aluminum.

3.5 Inlet

An essential part of the testing rig was a way of directing the flow through the turbine after passing over the weir to optimize inlet angle. Similarly, a backsplash inhibitor was needed to ensure that the water went through the crossflow turbine and out the bottom of the turbine without a large wave of turbidity behind the turbine closer to the weir. Based on the work conducted by Clark, the inlet of the casing needed to direct the water at a 20-degree angle starting 30 degrees down from the top dead center of the turbine. The backsplash in Clark's research very closely matched the radii of the turbine and provided only a big enough gap for the turbine to turn. Moreover, the inlet backsplash ramped the water down off under the turbine and allowed the water to continue down the flume. Figure 3.8 below shows Clark's Inlet and Backsplash Inhibitor mounted to a sharp crested weir.

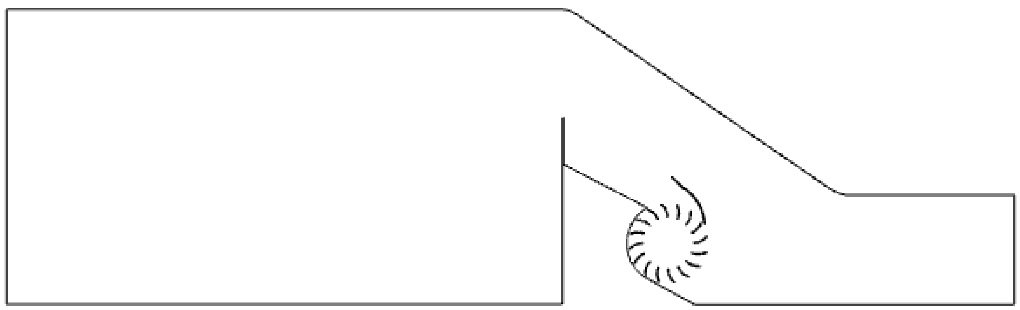

Figure 3.8: Clark Inlet with Sharp Crested Weir

After numerous iterations utilizing different materials and sizes, the best compromise for an inlet was selected. Figure 3.9 below shows the inlet chosen for the testing rig.

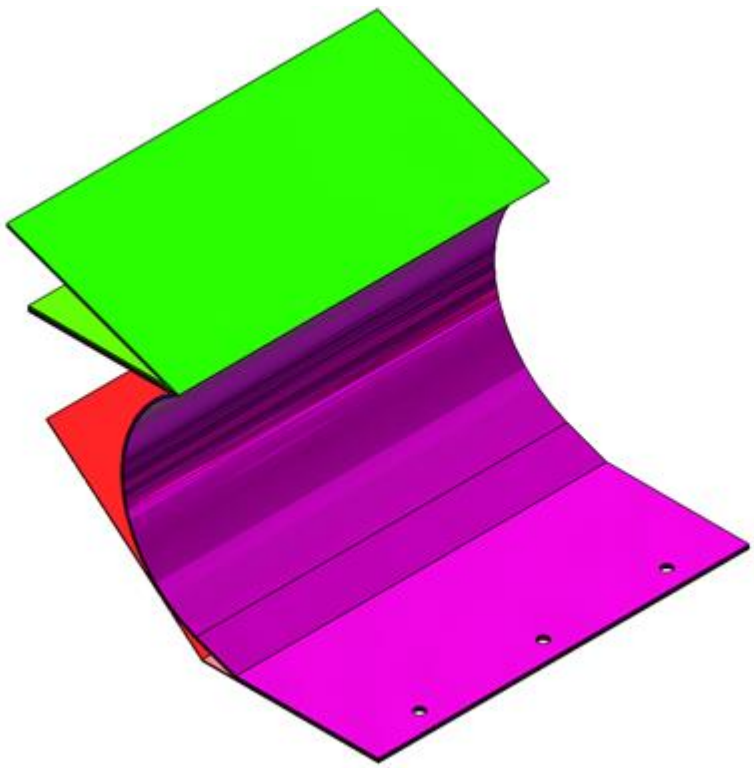

Figure 3.9: First Design Casing Inlet

The red component in the above figure would allow for the attachment of the backing to the Ogee weir. Due to the curvatures of the ogee weir, the red backing plate creates a flat surface for the other inlet components to sit stability against the weir without requiring additional components to be machined to move with the weir as the Inlet moves up with the turbine. This piece is made of a piece of gauge 14 aluminum sheet metal. This component has 3 holes drilled to ensure that it is lined up with the weir and the anchoring holes in the floor of the flume. The purple component in Figure 3.9 above acts as the back splash inhibitor that Clark showed. It is fitted to the turbine and when aligned with the holes for the red weir backing and the weir itself, allows the model turbine enough space to turn without friction. The backflow inhibitor is made of gauge 14 aluminum sheet metal and would allow for additional sizes and radii to easily be machined and swapped out as necessary to better fit around different turbine shapes and sizes. The green top cap in Figure 3.9 above is designed to allow the flow over the weir to enter the WCFT at a specified angle, 20 degrees from horizontal in this case. The green cap is made of gauge 14 aluminum and is connected to the purple backflow inhibitor by a quarter-20 bolt. In the actual model, the green top cap should be directly attached to the weir with a piece of gasketing or tape to prevent water leakage behind it.

Gauge 14 aluminum sheet metal was chosen for each of the components in the inflow for its ease of machinability, its low cost, high strength, and anticorrosive properties which is essential as it will be submerged in water for extended periods of time. These aspects of aluminum were important because only one inlet would be created to begin with, and it would be used in numerous tests. However, the cost for creating additional angles or backflow inhibitors for different turbines would be a nominal cost when compared to the rest of the project.

3.6 Turbine Placement

Turbine placement was a major component that underwent extensive design modeling. The turbine had to be easily raised and lowered, as well as able to be shifted in place down the flume diversion. Figure 3.10 shows how the turbine will be placed into the testing rig.

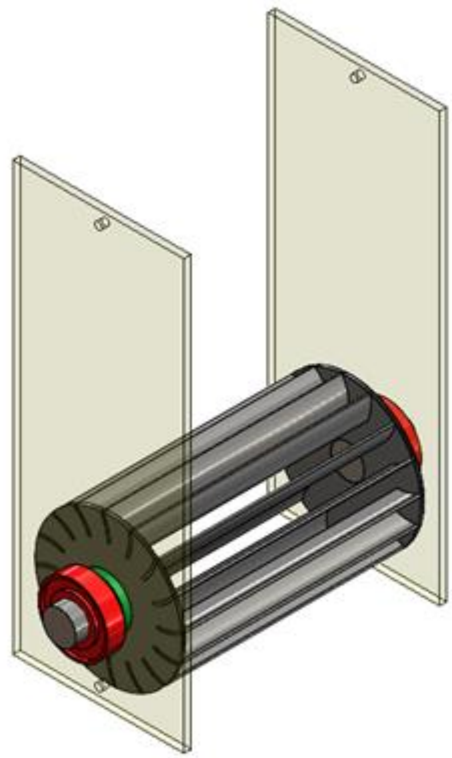

Figure 3.10: Fully Assembled Turbine Holding

The turbine holder allows for any horizontally aligned turbine to be tested in the testing rig. The model shown in Figure 3.10 above, has a 16-blade turbine modeled after Malkus' work. It would be attached to the rigid casing by a shaft cantilever in the plate holding the blades of the turbine. A lip seal, used to keep water in the diversion, would be fitted in the casing's acrylic panel to prevent water leakage. This is the green component which is shown sitting in the yellow acrylic walls. A ball bearing, red, helps to let the shaft rotate easily and could be fixed to an aluminum block to ensure that they stay level provided that the thickness of the casing wall is too thin to accommodate the full width of the bearing.

3.7 Outlet

The outlet of the casing was also modeled after the tests conducted by Clark as shown in Figure 3.11 below.

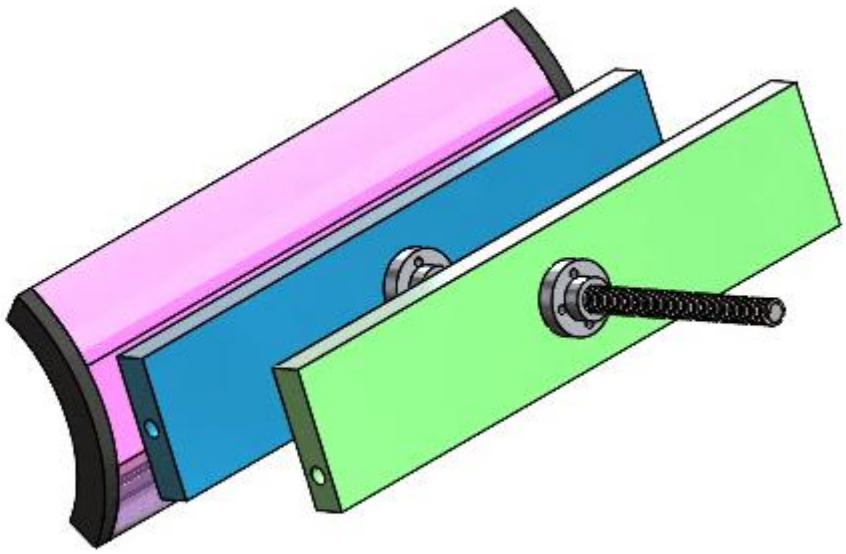

Figure 3.11: First Design Casing Backing

The outlet of the casing utilized four main components. The lead screw, which is fed through two ball nuts, allows the pink outlet to be brought closer to the turbine or further from the turbine. The pink outlet allows for the shape of the outlet to be quickly switched out by removing 4 screws. The pink outlet flow would be made of PVC pipe cut into 4 quadrants to ensure a rigid, cheap, and easy to machine. The black gasketing around the pink outlet allows for the outlet to be more watertight in the diversion and will be made of a gasket designed for sinks. Moreover, the PVC and gasketing both have anticorrosive properties that won't allow for the material to break down. The rear green plate is a 0.5-inch-thick aluminum plate that will house the lead screw and ball nuts for bringing the outlet closer to the turbine and angling the inlet compared to the turbine. The blue aluminum plate provides the same function as the green aluminum plate but acts as an additional stabilizer to keep the metal from moving under the weight of the water. If really interested in cutting costs, one could remove the second plate. Aluminum was chosen as the material for the angling plate because of its anti-corrosive properties, the precision one can get by machining it and the strength that can be obtained using it.

3.8 Prony Brake Connection

The Prony brake is a device that measures torque and subsequently power of a rotating shaft based on force required to stop the shaft when a predetermined force is applied at a known distance. The Prony brake must be kept dry in the area between the diversion wall and the flume wall. The Figure 3.12 below shows the Prony brake modeled in SolidWorks as it would work for the turbine testing rig. The red friction wheel would be attached to the rotating shaft of the turbine. A rope of known diameter, 3/16 inch in this model, is pulled by the friction wheel and extends upward into the overhang made of 1” square aluminum extrusions. One end is wrapped around a pulley secured to an L bracket. Attached to the rope that runs over the pulley is a notched mass set that has incremented masses at 5-gram intervals. The other end of the rope extending up from the friction wheel is attached to the purple scale in Figure 3.12. This scale directly sits on an aluminum rod that is secured to another L bracket. The mass set was chosen for the experimenter’s ability to adjust weights easily and in relatively small quantities. The scale was chosen for its ability to test up to 15 pounds of force as well as its precision. Lastly, the aluminum 1” square extrusions were chosen for their low cost and ease of assembly after manufacture. Moreover, the overhang won’t experience much force compared to the diversion and radial force from the turbine, so the extrusions will be strong enough to hold up the scale and mass set.

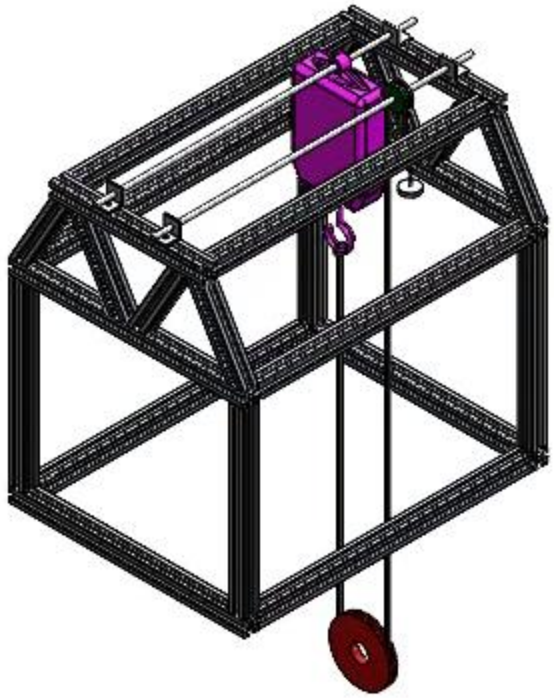

Figure 3.12: First Design Prony Brake and Overhang

3.9 Screen

The last major component required for the testing rig was the debris screen which allowed for tests to be conducted in obstructed flow conditions. As the most likely turbines being tested are those that will be attached to non-powered dams, it is safe to assume that screens will be implemented to protect the wildlife populations. The screen shown in Figure 3.13 below is constructed from 2 pieces of gauge 14 aluminum sheet metal cut into rectangles with one side missing and the center removed, and a screen cut to a nine-by-nine square. The screen is sandwiched between the pieces of sheet metal and bolts are fed through to lock the screen in place. The numerous holes drilled in the sheet metal allow for various screen sizes to be inserted as necessary for the test. The zinc plated hinge will be corrosion resistant and allows the screen to be directly attached and angled from the pink outflow. The other end of the sheet metal has holes predrilled for a rope to connect the screen to the weir.

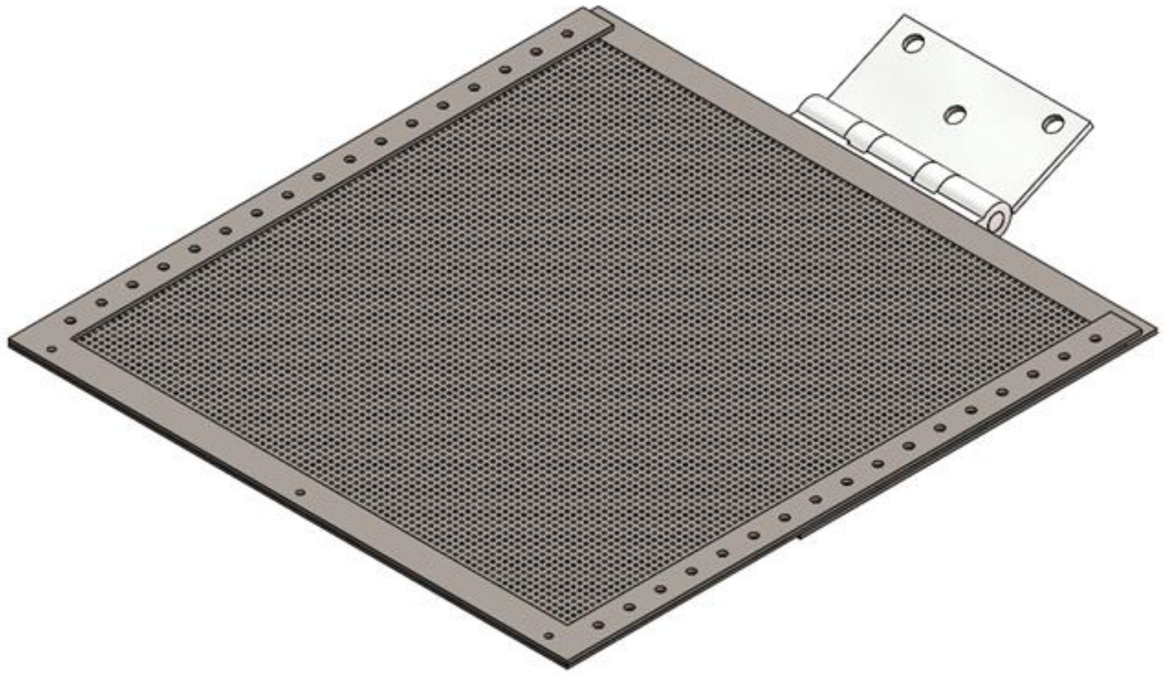

Figure 3.13: First Design Screen

3.10 Full Model

With each part completed, the first design of the testing rig was assembled in SolidWorks. Figure 3.14 below shows the completed testing rig as it would be assembled.

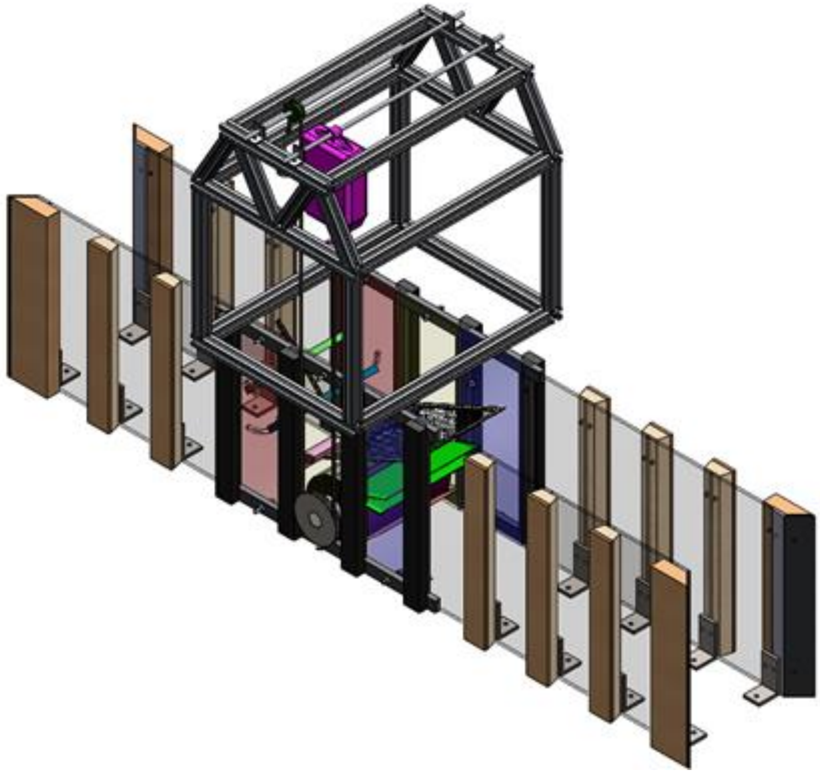

Figure 3.14: First Design Testing Rig Assembly

Chapter 4

Optimization of Testing Rig

4.1 Original Budget

Taking the first design as laid out in Chapter 4 above, produced the following budget in Table 4.1. Despite the number of iterations needed to achieve the first design as outlined in Chapter 4, the time required to machine, the amount of waste produced, and the cost of the full assembly was quite large.

Each category was broken down from the first design into: Diversion, Casing, Miscellaneous, Inflow, Outflow, and Overhang. The components going into each of these areas was more closely examined. Where overbuilt, less robust pieces were chosen to reduce cost. Where excess material was originally called for, alternatives were found to reduce wasted material and machining time. Reducing waste, optimizing material choice, and using material that required less machining minimized the time and cost required to build the second design. Table 4.1below shows the budget suggested after completion of the full model shown in Chapter 4.

Table 4.1: First Design Cost Breakdown

Section	Cost	% of Total
Diversion	$154.53	11.42%
Casing	$229.69	16.98%
Miscellaneous	$91.70	6.78%
Inflow/Weir	$186.78	13.81%
Outflows	$234.11	17.31%
Overhang	$455.84	33.70%
Total	$1,352.65	100.00%

4.2 Material Selection

The type of material was a large consideration for the development of the testing rig. For the diversion there were three main choices for the material to use, each with its own benefits and disadvantages. First, wood was considered. The advantages of wood were that it would be readily available with little to no lead time. Wood is easy to alter, and wood is cheap, so if larger quantities were needed wood provided a pragmatic choice. Wood does however have numerous disadvantages that would make it less than ideal for our purposes. Wood lacks the refinement of manufacturing that other materials have- for instance, wood bows very easily, and it is likely that the wood thickness and bowing will vary between pieces. Moreover, wood when left in water may start to deteriorate, or at the very least swell. The former concern was determined that it could be dealt with if pieces were cut small enough but working to fix the problem would not be an optimal solution. The latter concern was investigated further. Stain was considered; however, this was determined to only delay the inevitable rotting of the wood over time. Lacquers were considered, but this didn't guarantee the preservation of the material for the additional work and cost. Lastly, waxing of the wood was considered. This is a process in which wooden beehives are dipped in boiling wax so that the moisture in the wood gets replaced with wax. This is done to ensure that the beehives can stand up to the elements for extended periods of time. While considered as a possible option, the idea of using wood for the outer shell of the diversion was dropped due to these problems.

Metals were also considered for building material. The high strength of steel would allow for less material to be needed. However, it was quickly apparent that the steel would rust after continual subjection to water. Moreover, the steel would be harder to machine to what was needed. Aluminum was considered as it is relatively lightweight, cheap, easy to manufacture, and strong enough for the purposes of this project. Metal remained the best contender due to these properties but would impart a higher cost than wood.

Furthermore, plexiglass or acrylic were considered for the material of the diversion. The primary benefit of this material was that it could stand up to the water, and that it was transparent, allowing the experimenters the ability to view the test. The main concern with acrylics and plexiglass was that it is more liable to shatter if not cut or drilled properly. Outside of the diversion, acrylic was not suitable for much else.

In addition to these three main building materials, High Density Polyethylene, HDPE, or other plastics were considered. The material would be easy to machine, rigid, and not subjected to damage if submerged. The cost of the material was considered appropriate in thin sections but would be too expensive if used in large quantities.

4.3 Budget, Cost, and Improvements

Figure 4.1 below shows the second design testing rig in the flume.

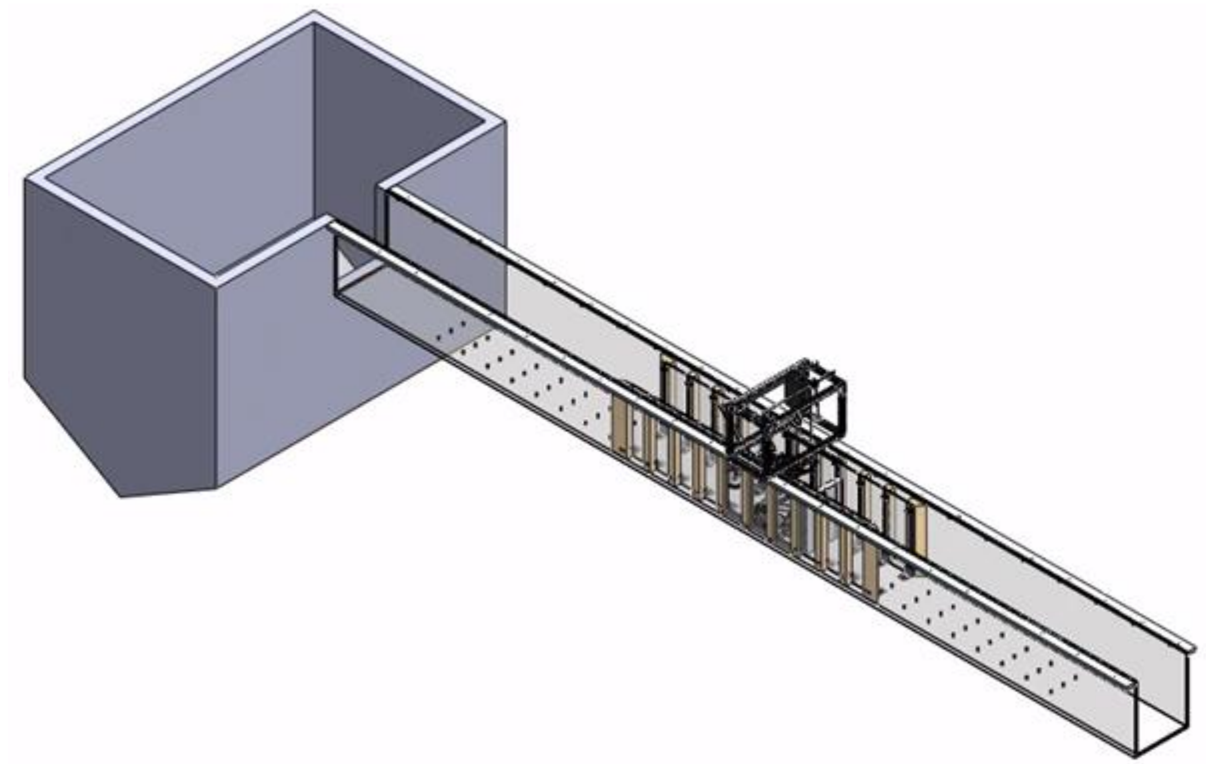

Figure 4.1: Second Design Full Model and Flume Assembly

4.3.1 Diversion Optimization

4.3.1.1 Viewing Panels

The first area of optimization was the diversion panels. In the first design, the panels were ¼ inch thick. Calculations, shown below were performed to determine the force applied to the panels. Figure 4.2below shows the diagrams associated with calculations for hydrostatic pressure (Gerhart,Gerhart, Hochstein, 2016).

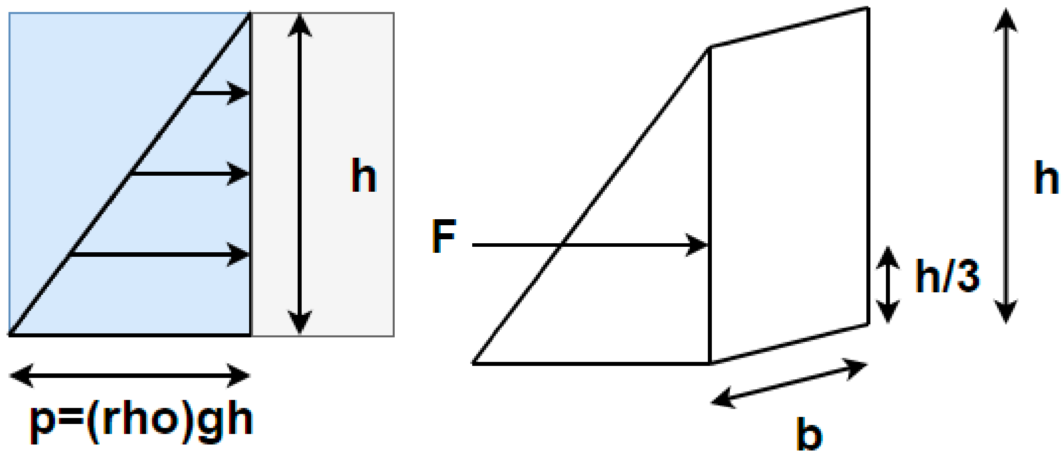

Figure 4.2: Hydrostatic Pressure Diagram

If it is assumed that the six-inch sections of acrylic have ¾ inch on either side supported by the wooden buttresses, the width, b, becomes 4.5 inches. The following equations can be used to show the force of the water (Gerhart,Gerhart, Hochstein, 2016).

$$p = \rho g h \quad (1)$$

$$p = 62.4\frac{lbs}{ft^3} * 15in * \frac{1ft}{12\,in} \quad (2)$$

$$p = 78\frac{lbs}{ft^2} \quad (3)$$

$$A = b * h \quad (4)$$

$$A = 4.5in * 15in * \frac{1\,ft^2}{144\,in^2} \quad (5)$$

$$A = 0.46875\,ft^2 \quad (6)$$

$$P = 0.5 * 78\frac{lbs}{ft^2} * 0.46875ft^2 \quad (7)$$

$$P = 18.28125\,lbs \quad (8)$$

Figure 4.3 below shows the force calculated as it would cause bending stress in the acrylic viewing panels.

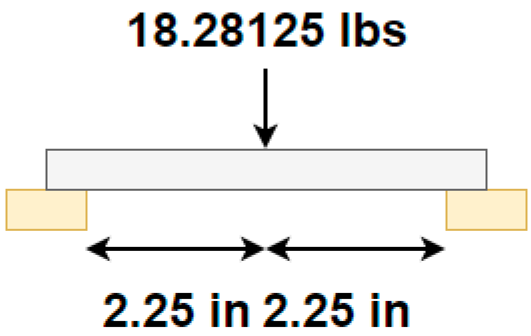

Figure 4.3: Beam in Bending Figure

If the viewing panel is made of acrylic and a bending equation is considered where both ends are fixed. A bending moment can be calculated using the equations below (Hibbeler, 2016).

$$M_{AB} = \frac{PL}{8} \quad (9)$$

$$M_{AB} = \frac{18.28125lb * 4.5in}{8} \quad (10)$$

$$M_{AB} = 10.2832lb - in \quad (11)$$

$$\sigma = \frac{M_{AB}C}{I} \quad (12)$$

$$I_{0.1875} = \frac{bd^3}{12} \quad (13)$$

$$I_{0.1875} = \frac{4.5in * (0.1875in)^3}{12} \quad (14)$$

$$I_{0.1875} = .002471923828in^4 \quad (15)$$

$$\sigma = \frac{10.2832lb - in * 0.09375\ in}{0.002471923828\ in^4} \quad (16)$$

$$\sigma = 389.9999\ \frac{lb}{in^2} \quad (17)$$

According to the acrylic and plastic manufacturer Curbell, the tensile strength of Acrylic is 10,000 pounds per square inch. Since the anticipated stress applied to the acrylic sheet was only found to be 389.9999 pounds per square inch for the 3/16-inch-thick acrylic, it is safe to assume that this is strong enough to withstand the hydrostatic pressure of the water against the panels of the diversion. (Curbell Plastics). Figure 4.4 below shows the viewing panels for the diversion.

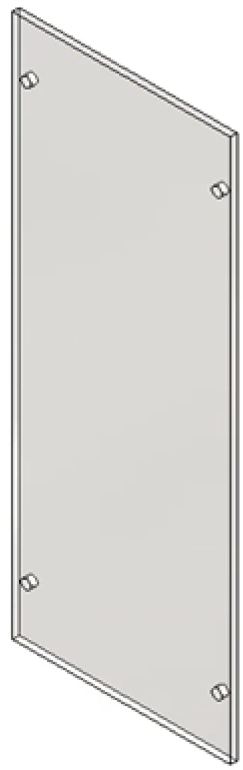

Figure 4.4: Optimized Viewing Panel for Diversion

It should be noted, that while hydrostatic pressure force is given as the main force to be considered, the flow is moving and hence hydrodynamic forces will also act on the panels.

4.3.1.2 Wood Buttresses

The wooden buttresses designed in the first design were changed to reduce both the amount of wasted material and the amount of time required to produce them. Initially, the wooden buttress supports required the experimenter to plane down 0.5 inches of wood from a two by four board and glue them to a ¼ inch thick piece of plywood. The work required in this phase alone would have far exceeded the work required for the rest of the diversion. The two by four board was replaced with a two-by-two board cut into 15 inch increments. As the role of the wood supports were to distribute the pressure from the walls of the diversion to the flume itself, the strength of compression required was minimal, therefore the change was determined to have very little bearing from a strength perspective. As the two by two is nominally 1.5 inches wide, the channel width was reduced slightly to accommodate for the slightly thicker wood piece, however, it was decided that the great reduction in time and waste, as well as the reduction in cost was worth the decrease in channel width from 9 inches to 8.625 inches, after accounting for the change in acrylic thickness, seemed reasonable. In addition to the time, waste, and cost savings, this simple modification allowed the Prony brake attachment to have additional space to attach to the shaft. To further improve the design and save space, the bolts attaching the diversion were counterbored. The shape was changed from a trapezoid to a square to reduce waste of the lumber having to be cut as well. Figure 4.5 shows the diversion buttress.

Figure 4.5: Optimized Wooden Buttress for Diversion

4.3.1.3 Corner

Like the wood used in the buttress supports, the wood used for the corner diversion contraction and expansions was originally supposed to be produced by planning down two by four boards from 1.5 inches to 1.25 inches. Again, this would have led to considerable waste and extensive work. With the slight reduction of the channel width due to the buttress alteration and the thinning of the acrylic, the two by four board no longer needed to be planed down. The two by four only needed to be cut into 15-inch sections and then cut with a 45-degree angle on one side. Moreover, to further save costs, the aluminum support called for on the 45 angle of the corner wood was removed in favor of using a simple waterproofing over the wood through either a lacquer, stain, or rubberized coating. This helped to reduce cost and save machining time. Figure 4.6 below shows the wooden corner buttress.

Figure 4.6: Optimized Wooden Corner Buttress for Diversion

4.3.1.4 Aluminum Corner Support

With the alteration in the wood corner came an alteration in the corner protection. The two pieces of aluminum attached to the wooden corner support in the first design diversion outlined in chapter 3 was excessive as it only served to reduce water and act as a shim for the L bracket attaching the diversion panel to the floor of the flume and the corner. With the thickness reduction of the acrylic, the aluminum support was also reduced in thickness to 3/16 of an inch. Figure 4.7 below shows the aluminum corner support utilized.

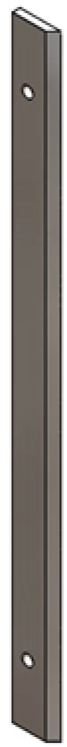

Figure 4.7: Optimized Aluminum Support for Diversion

The second design for the testing rig diversion is shown below in Figure 4.8.

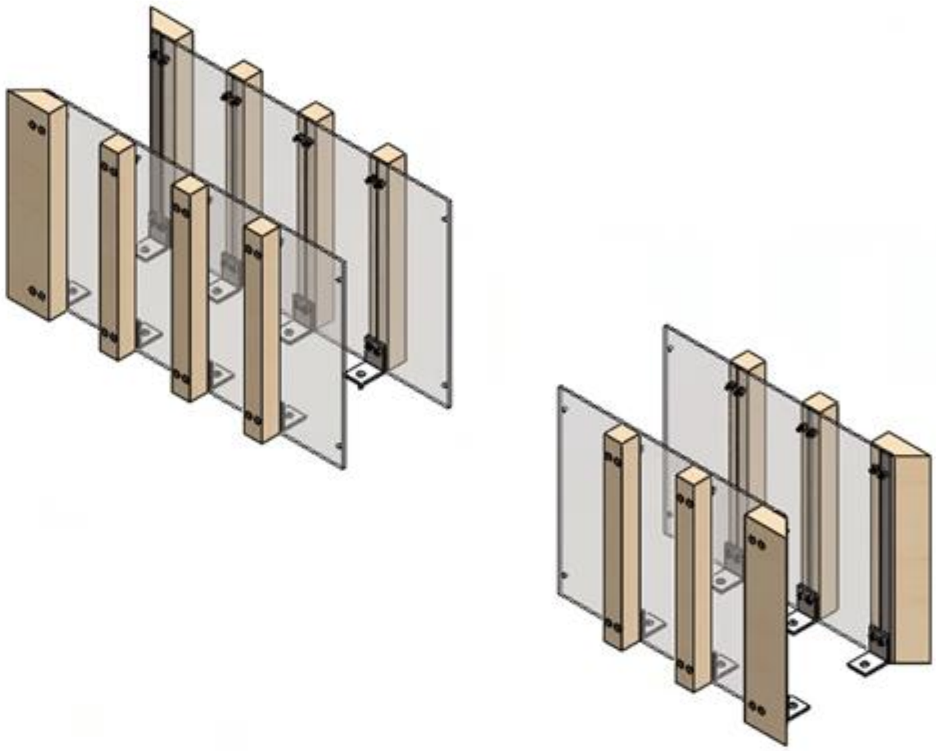

Figure 4.8: Second Design Flume Diversion

4.3.2 Casing Optimization

4.3.2.1 Brace A

Brace A, which holds the three panels of the casing in place along the top and bottom was altered slightly. First, the length of each brace was reduced from 21 inches to 19.5 inches. Second, the thickness of the modeled bar was reduced from ½ of an inch to 7/16 of an inch. Neither of these changes helped to reduce waste, in fact both led to increased waste as an eight-foot bar long 0.5-inch-thick aluminum bar was required in the first design and the second design. However, these alterations helped to allow for further improvements in the casing optimization. The other major change in Brace A that the spacing of the bolt holes holding the panels was modified. Before, the bolts held in place in Brace A closer to the floor of the flume would have hit the turbine. By changing the number of holes in Brace A from three to six, the concern of overlap was eliminated. Figure 4.9below shows Brace A after the optimization.

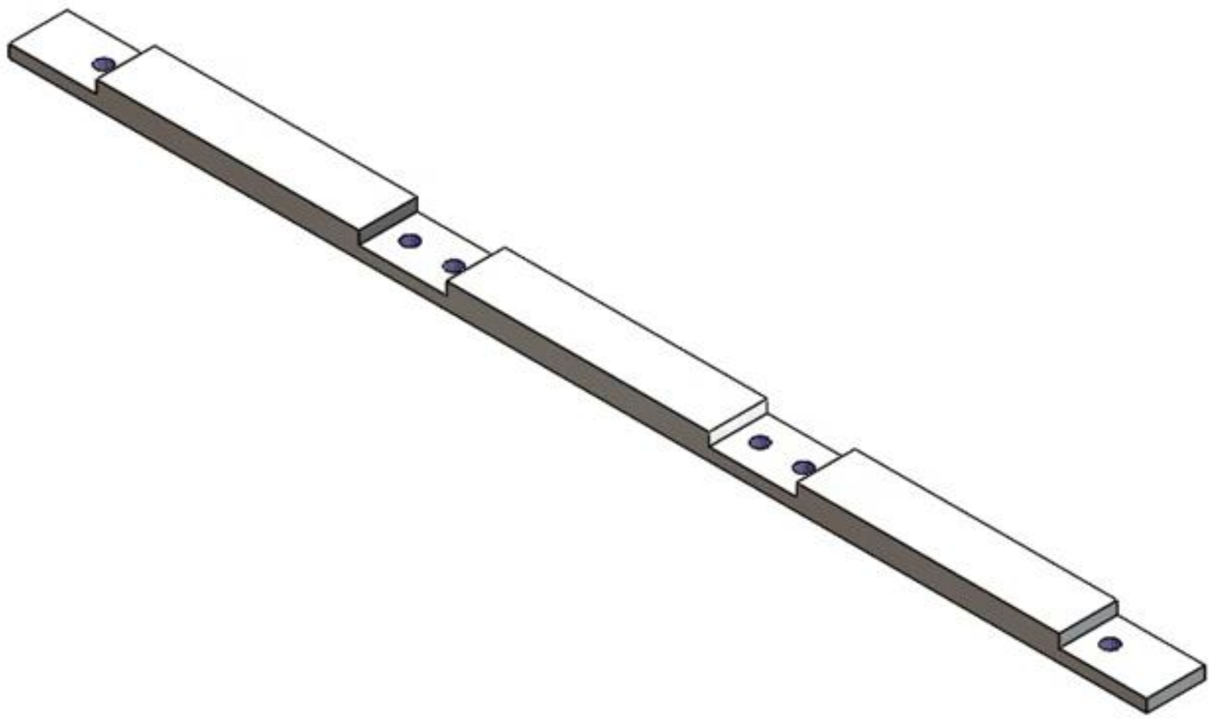

Figure 4.9: Optimized Brace A for Casing

4.3.2.2 Brace B

Like Brace A, Brace B didn't see a sourcing change that reduced waste and again increased the amount of waste. The thickness of the bar utilized was again reduced from ½ of an inch thick to 7/16 of an inch thick and the width of the bar was increased from 1 inch wide to 1.5 inches wide. The wider bar allowed for a larger overlap between the lap joints holding Brace A and Brace B together. Moreover, the increased width allowed for the alteration in the bolting pattern outlined in Brace A to be achieved. If this had not been done, the two bolts feeding through Brace A would have needed to be closer together and less support would have been offered to the casing panels. Figure 4.10 below shows Brace B for the casing following optimization.

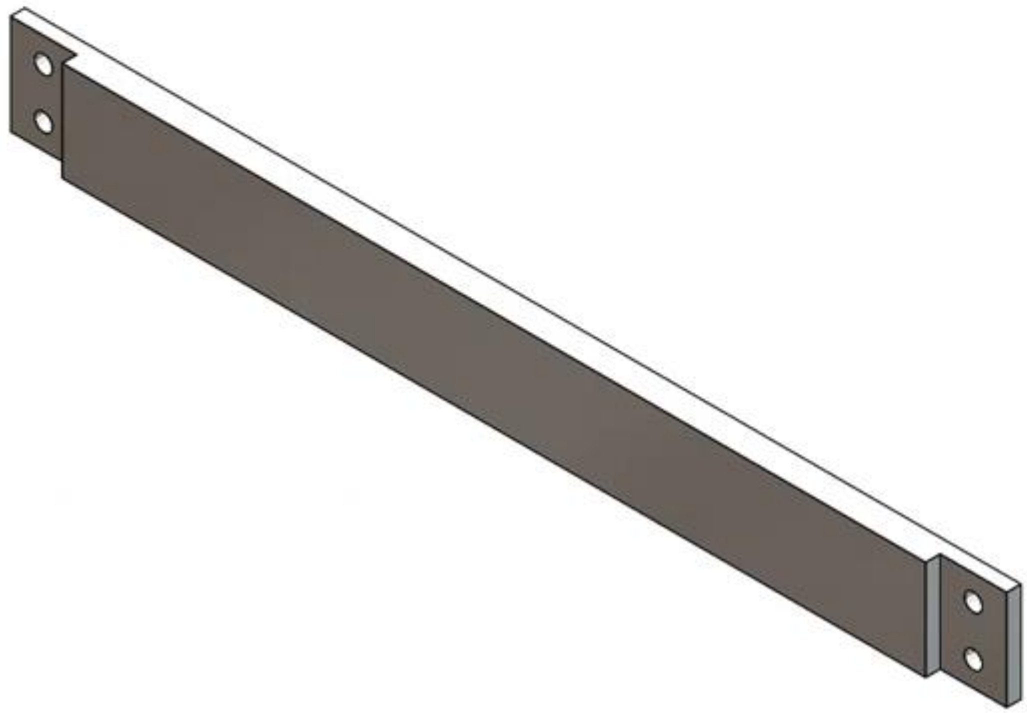

Figure 4.10: Optimized Brace B for Casing

4.3.2.3 Brace C

Brace C did not exist in the first design outlined in Chapter 3, but rather it is an additional component that builds off Brace B. Brace C helped to close the gap between the acrylic of the diversion and acrylic of the casing. Brace C helped to support the acrylic from the diversion with a wooden support as Brace C directly transmitted the load from the connection of the diversion and casing to the central wood buttress. Figure 4.11 below shows Brace C for the casing after the optimization.

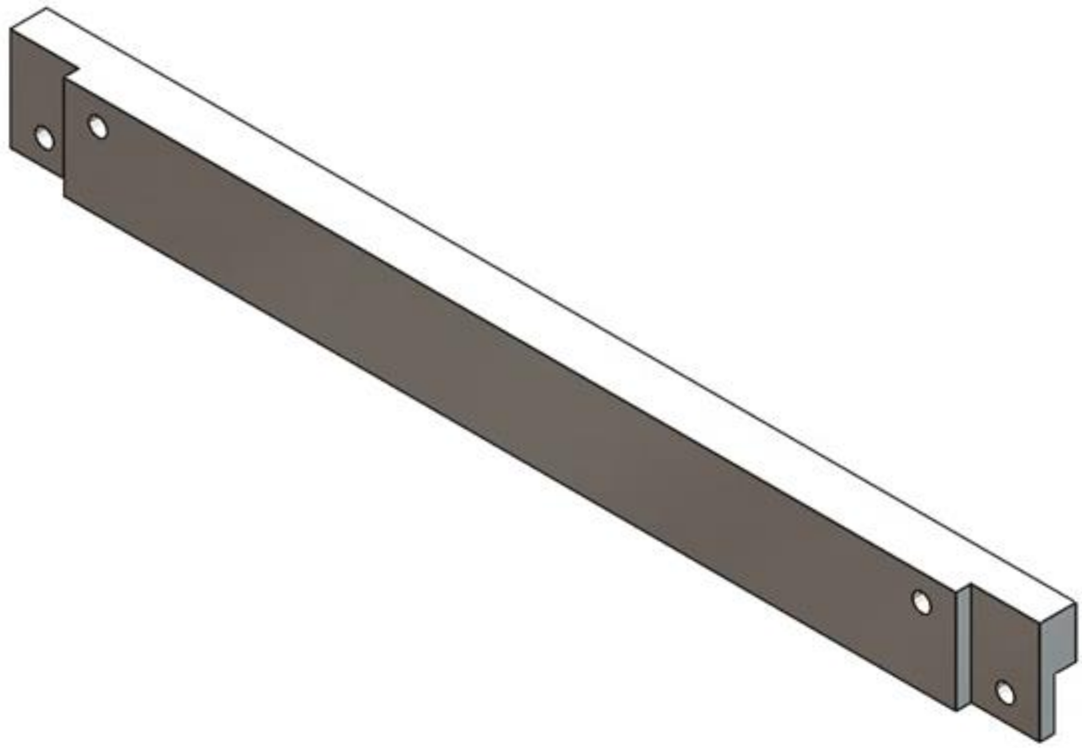

Figure 4.11: Optimized Brace C for Casing

4.3.2.4 Wooden Supports

The wood buttress supports for the casing were modified from plywood that had to be sanded down to one by two boards that are nominally 0.75 by 1.5-inch boards. The alteration reduced the cost of the materials dramatically. In addition to this alteration, the wooden supports were altered so that there would be one designed for the outer connection of the panels of the diversion to the panels of the casing on either connection side as well as a wooden support for the panels in the casing exclusively. Figure 4.12 below shows the Casing Wood buttresses A, Central, and B respectively.

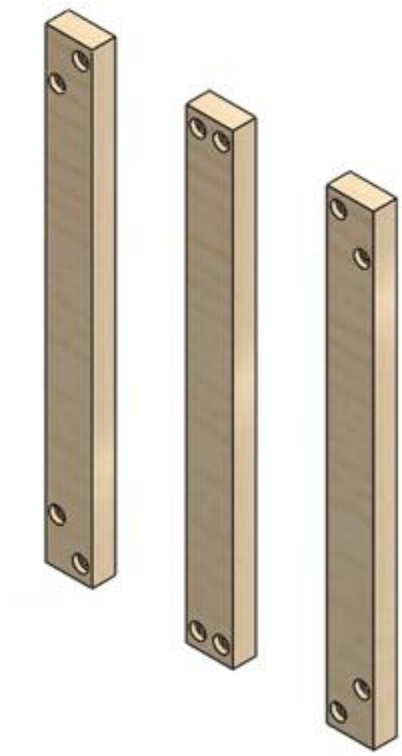

Figure 4.12: Optimized Wooden Supports for Casing

4.3.2.5 Viewing Panel

The viewing panel for the casing was thickened during the optimization process from ¼ inch to ½ inch. This decision was made to make the thickness of the viewing plate equivalent to the other panels in the casing. Along with this, since the bolt pattern of the casing changed from six on one side of the casing to twelve, the holes drilled in the casing also changed from two in the center of the plate to one near each corner. Figure 4.13 below shows the viewing panel after optimization.

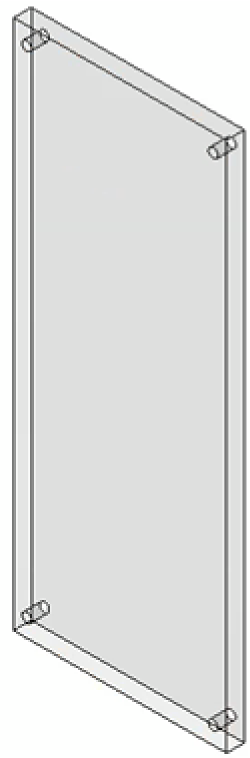

Figure 4.13: Optimized Viewing Panel for Casing

4.3.2.6 Turbine Holding Panel

Due to the possible radial forces experienced on the turbine holding panel from the water hitting the turbine, the thickness of the casing panels needed to be altered. Aluminum plates were considered as originally laid out in Chapter 3, but the ½ inch thickness was prohibitively expensive for the two holding plates. This helped to reduce the cost of the turbine holding panel, made it easier to move, and allowed for the experimenters to view the turbine while tests were being done. Additionally, the bolt hole locations had to be changed to prevent interference between the turbine and bolts. Figure 4.14 below shows the turbine holding panel after optimization.

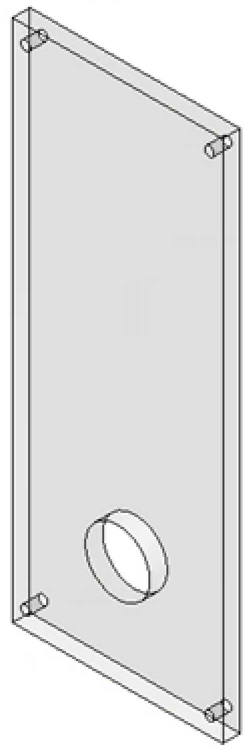

Figure 4.14: Optimized Turbine Holding Panel for Casing

4.3.2.7 Angling Panel

The original concern in chapter 3 was that the angling plate cuts could cause the acrylic to break rather easily if an inexperienced cutter tried to perform the cuts, therefore, aluminum was considered when only ¼ inch thicknesses were assumed. However, like the turbine holding plate, with the increase in thickness and subsequent increase in strength, it was determined that the angling plate could be converted to acrylic to improve visibility and reduce costs. Furthermore, as with the other two casing panels, the bolt hole positions were moved. Figure 4.15 below shows the angling panel for the casing following optimization.

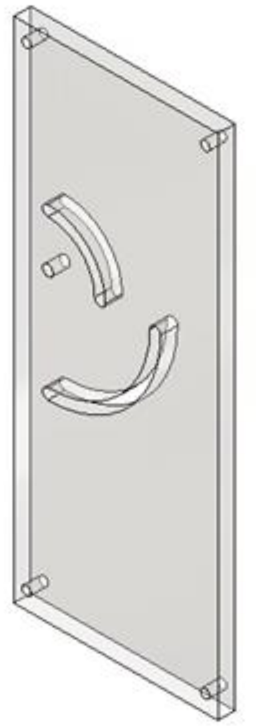

Figure 4.15: Optimized Angling Panel for Casing

Figure 4.16 below shows the assembly of the casing after the optimization.

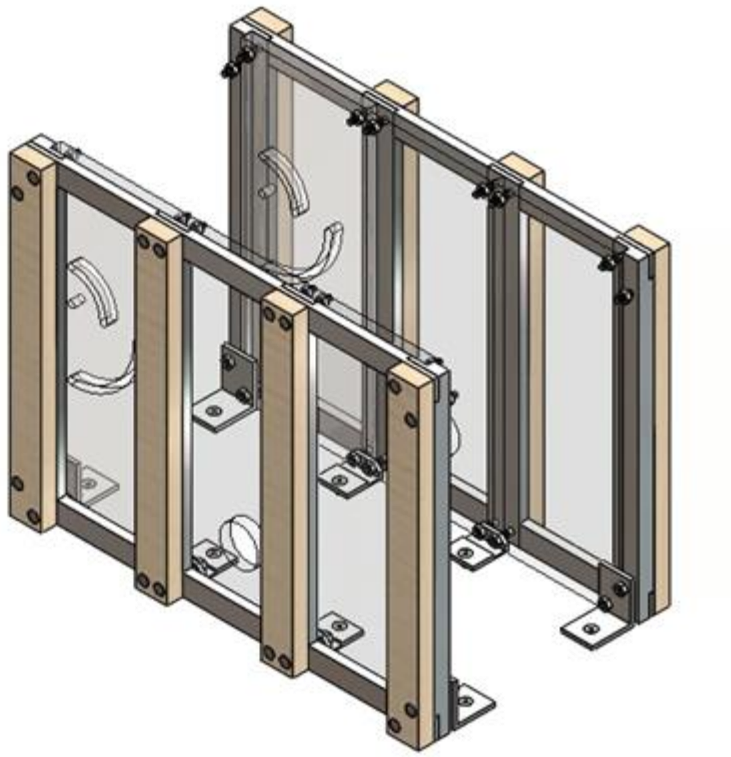

Figure 4.16: Second Design Casing

4.3.3 Other Optimization

4.3.3.1 Diversion Bolts

Where it made financial sense, bolts that were originally designed to be quarter-20 bolts, such as in the outflow connections, were replaced with #6-32 bolts. Since bolts overall, are overengineered, and can hold considerably more weight than would be experienced in any scenario in the testing rig, the bolt modification was deemed as a worthwhile endeavor. This helped to reduce the cost marginally but helped to show that all areas were considered. Figure 4.17 below shows the size comparison between the two bolts.

Figure 4.17: Bolt Size Comparison- Quarter 20 vs. Number 6

4.3.3.2 L Brackets

The L Brackets, which in Chapter 3 were all the exact same, were specialized. Two of the L brackets models are the exact same, except that the orientation of the bolts is flipped, these are intended for the connection of the casing to the diversion. One L bracket model is shortened and chamfered to fit over the aluminum of the inlet flow and backflow inhibitor and under the weir. In addition to this, by altering the positioning of the bolt holes in the wooden buttresses, the stock size of the L Aluminum extrusion could be reduced from 3-inch leg extrusions to 2-inch leg extrusions. Moreover, the thickness of the extrusion was reduced from ¼ inch to 3/16 inch. Like the bolts, it was determined that the force that the L extrusions could take prior to yielding was far more than the force ever present in the normal working scenarios of the testing rig. Lastly, to assist with positioning, counter sinks were added to accurately line the L brackets up with the anchoring holes giving the casing and diversion added rigidity. Figure 4.18 below shows the L brackets following optimization.

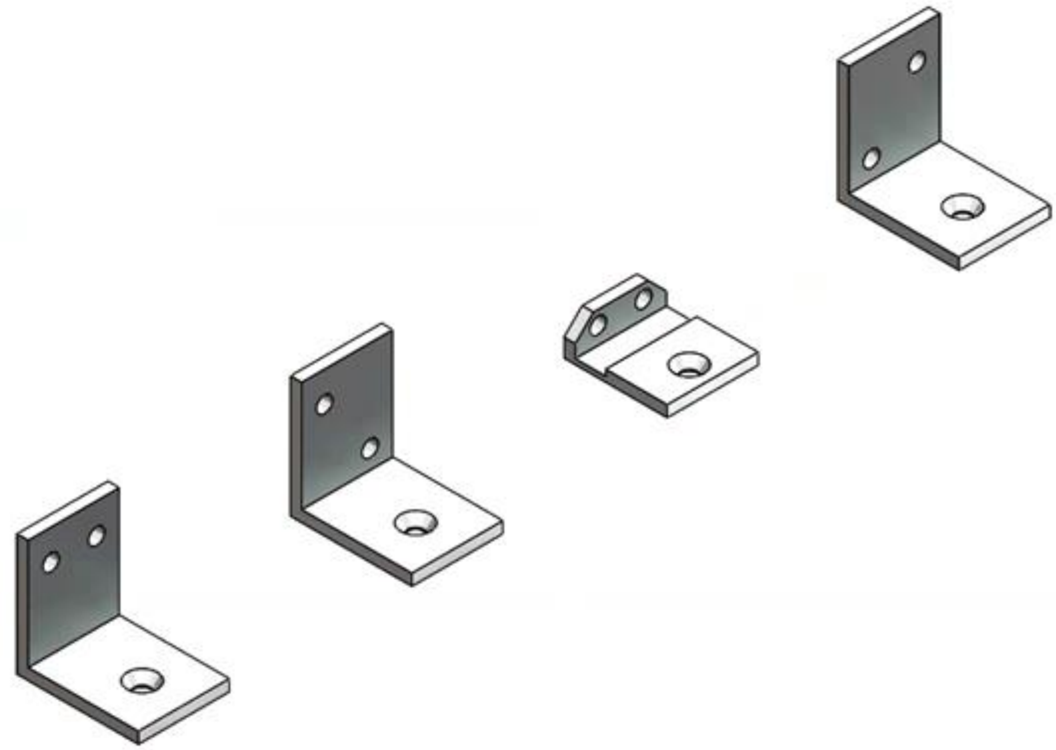

Figure 4.18: Optimized L Brackets -Diversion, A, Casing, B

4.3.4 Weir and Inflow Optimization:

4.3.4.1 Metal Selection

For the weir and inflow components, the metal thickness was changed from gauge 14 aluminum to gauge 20 aluminum or a change from 0.064 inches to 0.032 inches in thickness. This lowered the cost of the aluminum and made the components easier to cut and bend to shape, but it lowered the rigidity and structural integrity of the weir and inflow components. Figure 4.19 below shows the aluminum inlet pieces to be created.

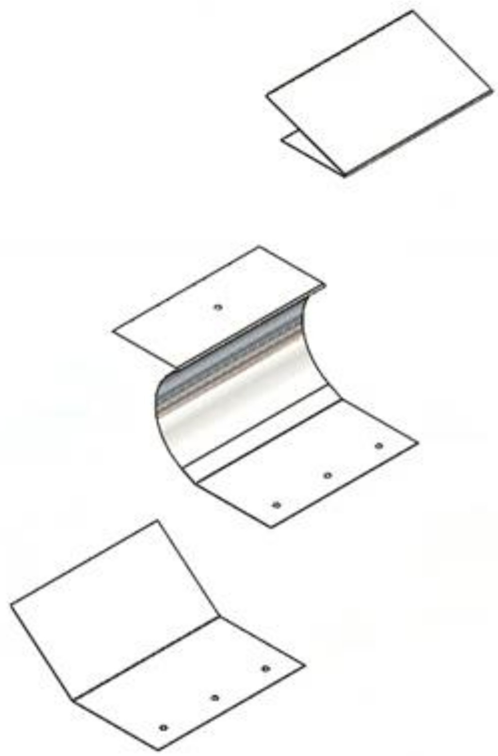

Figure 4.19: Optimized Metal Inlet Components

4.3.4.2 Rigid Boards

From the design in chapter 3 the only modifications made to the inflows was that each inflow had the rigid HDPE added in the same manner as the weir. With the reduction in aluminum sheet thickness, the HDPE greatly helped to strengthen the inflow portions against water pouring over the top of the weir. Despite the increased cost associated with more polyethylene, the cost was nearly the same after lowering the thickness of the aluminum sheet metal. Moreover, the HDPE helped to reduce the bending of the aluminum much more than the thicker only metal. Furthermore, although the quantity of the working increased, the actual difficulty of creating the components for the inlet and weir decreased with thinner aluminum pieces. Figure 4.20 below shows the HDPE inserts for the weir and inlet components.

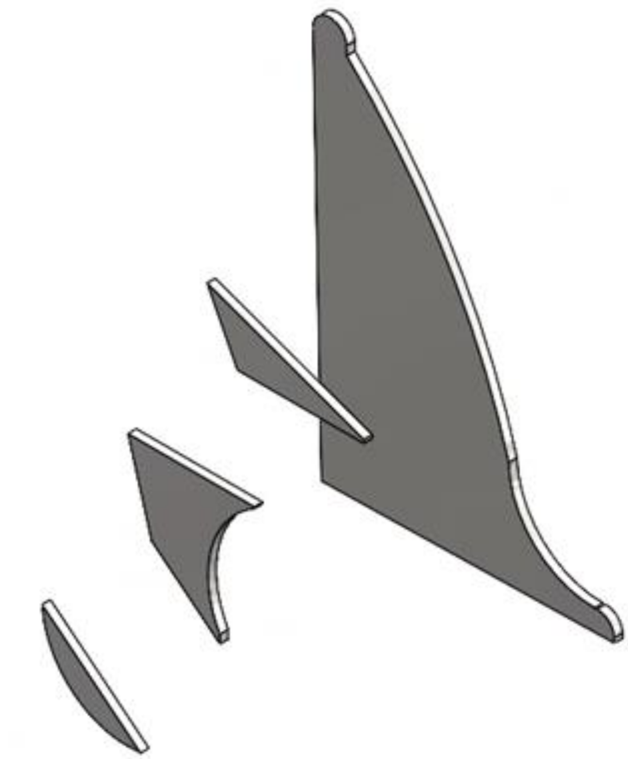

Figure 4.20: Optimized HDPE Support for Inlet and Weir

4.3.4.3 Welding

The last major modification to the weir and inlet components from chapter 3 was that the weir was broken down from one large piece to three much smaller pieces. The three pieces would need to be welded together after each piece was cut and shaped to form the weir itself. This modification allowed for smaller pieces of sheet metal to be purchased which helped to lower the cost and waste. Moreover, by using smaller pieces of aluminum, the manufacturer was more able to easily bend the material into whatever shape was desired. With this came a wider margin of error as now if a mistake is made, the manufacturer can either start over with one of the three sections at little loss, take the time to fix the area on a smaller piece of aluminum, or can simply weld over the mistakes with the lip of the next piece. Figure 4.21 shows the weir components.

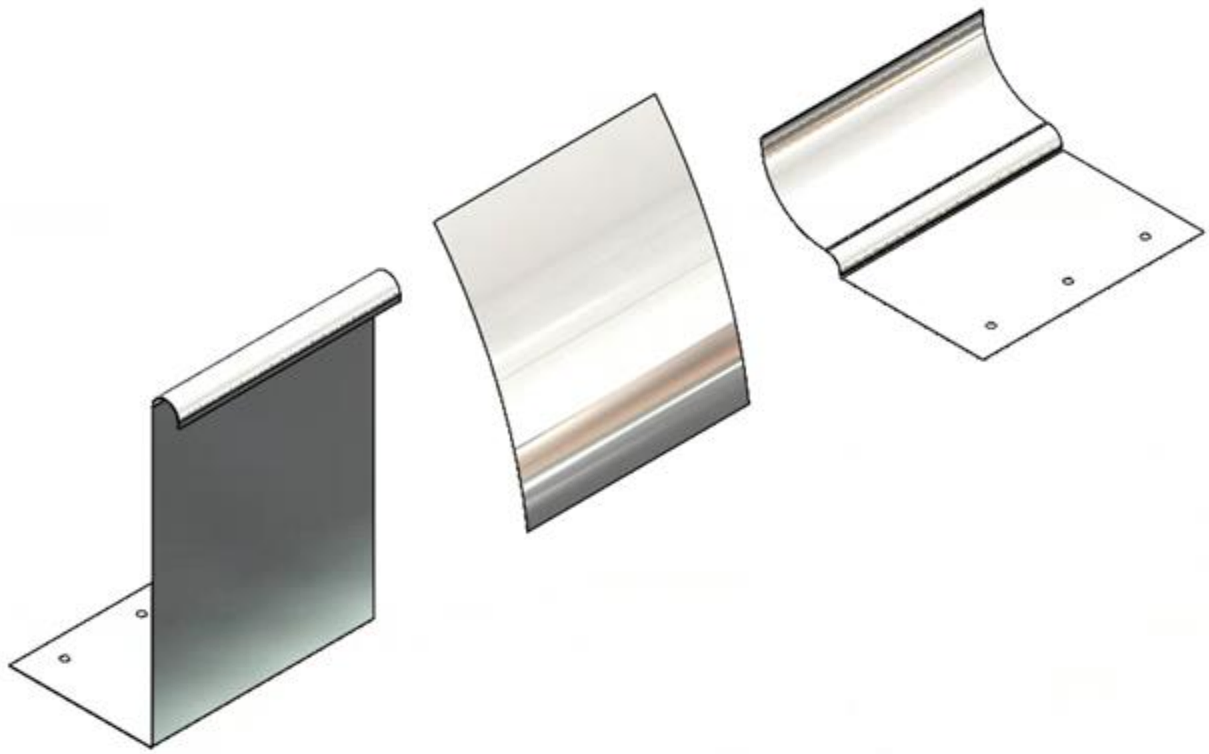

Figure 4.21: Optimized Weir Metal Pieces to be Welded

Figure 4.22 below shows the weir pieces, after assembly with the internal HDPE supports, connected to the other aluminum inlet components with their internal HDPE supports. This serves as the assembly of the second design of weir and inlets.

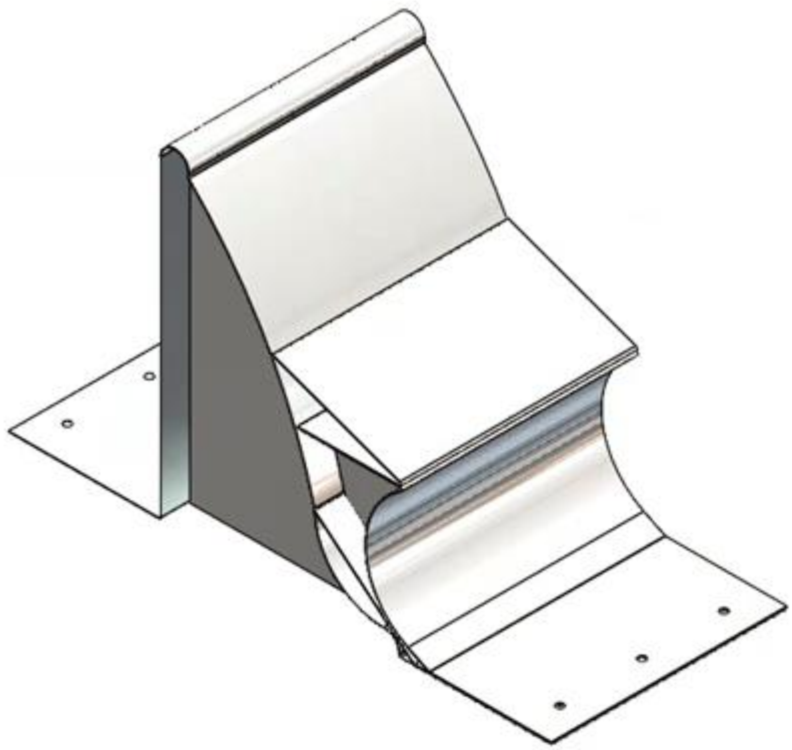

Figure 4.22: Second Design Weir and Inflow Model

4.3.5 Screen and Outflow Optimization

4.3.5.1 Screen Hold A

Overall, the Screen Hold A changed only slightly in size between the first design and the second design. The width of the part was reduced to 8.675 inches wide to accommodate for the thinner channel within the flume. Figure 4.23 below shows Screen Hold A after the optimization.

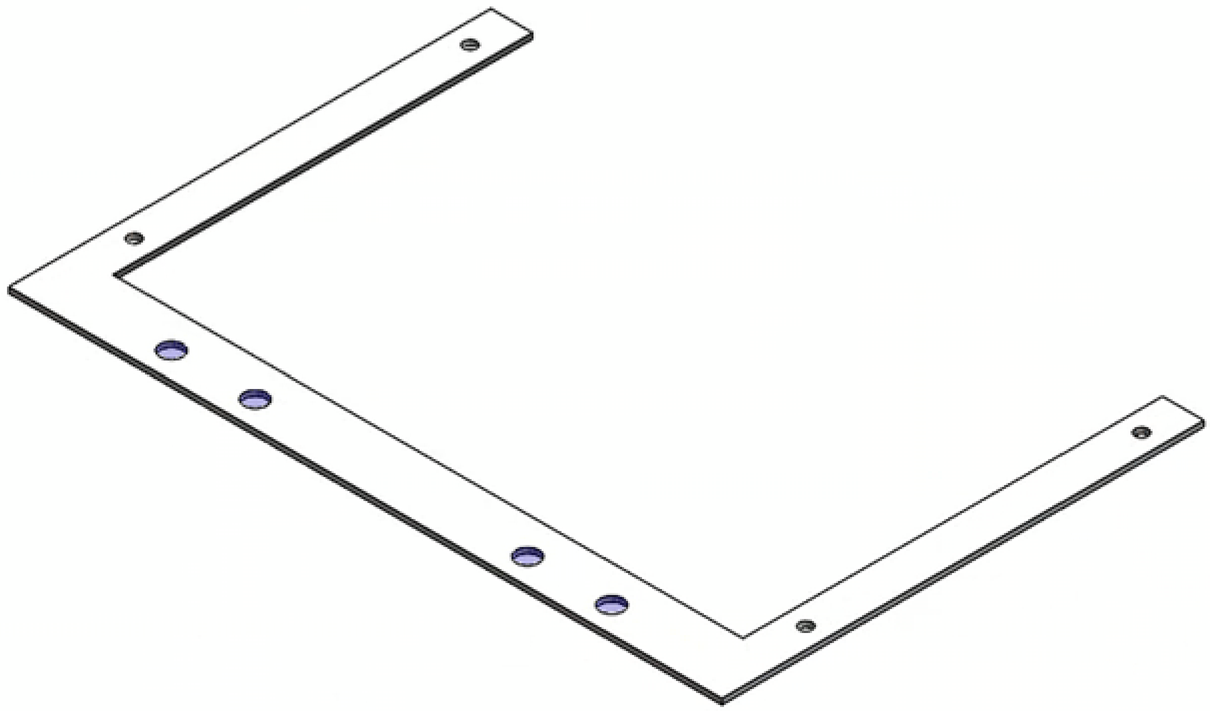

Figure 4.23: Optimized Screen Hold A

4.3.5.2 Screen Hold B

Similar to Screen Hold A, Screen Hold B did not change except in size between Chapter 3 and Chapter 4. Figure 4.24 below shows the second design of Screen Hold B.

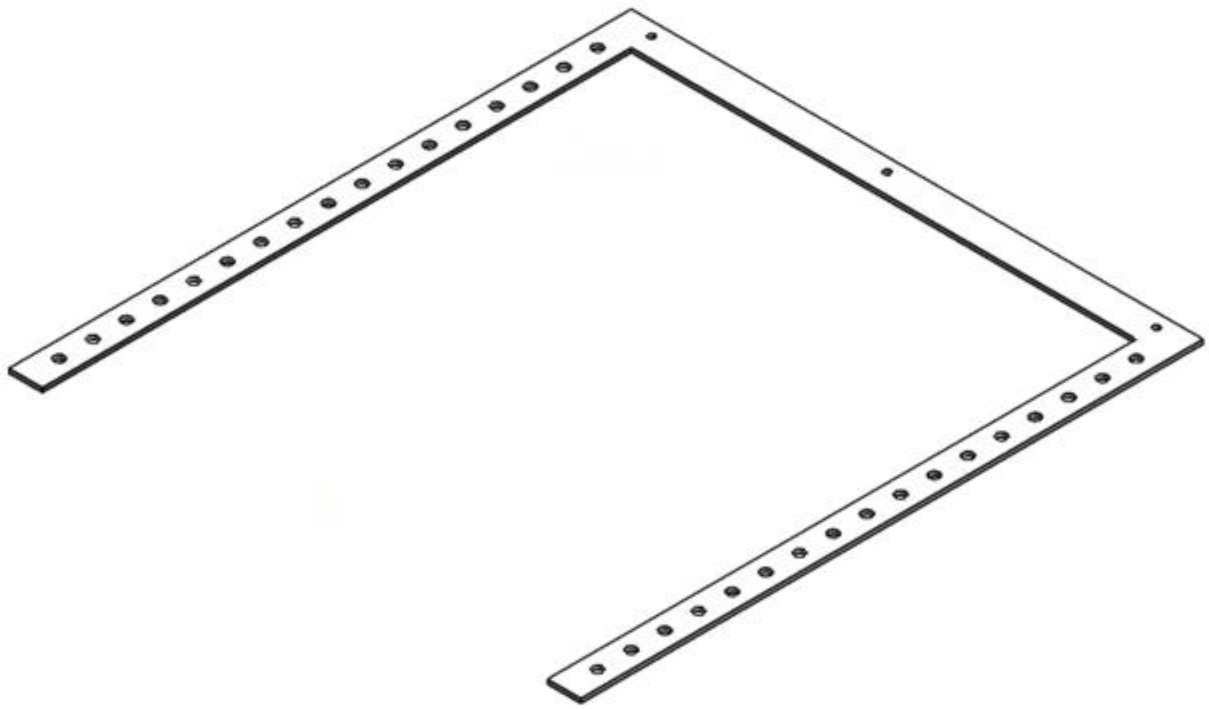

Figure 4.24: Optimized Screen Hold B

4.3.5.3 Outflow Backing

The outflow backing and gasket changed in the number and location of cuts between the first design and the second design. In the first design, the outflow only had 1 hinge and was held in place using a lead screw. The flat cut along the outer radius of the PVC is still present, however, instead of a through hole connecting a leadscrew via a ball nut, two holes will hold the positioning pole in place. The changes increased the amount of machining slightly, but the change to a positioning pole from a lead screw greatly reduced the cost. Additional cuts were changed, and the bolts were flipped over and altered so that flow was not restricted. Figure 4.25 below shows the outflow manufactured from PVC pipe and gasket designed for faucets.

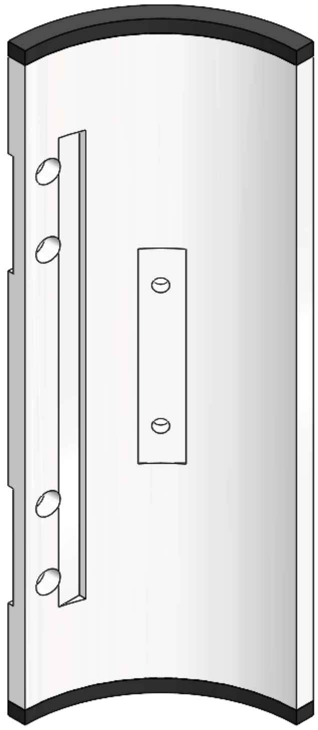

Figure 4.25: Optimized Outflow and Gasketing

4.3.5.4 Angling Plates

The angling plates were altered to accommodate the positioning pole by replacing the clearance hole for a ⅜ inch lead screw with ½ inch square clearance hole. The position of the clearance holes designed for all thread were moved toward the outside of the angling plates. Moreover, the clearance holes for the all thread were reduced in size to accommodate quarter-20 all thread. Lastly, the near angling plate added two #6-32 clearance holes to attach the bracket for the positioning pole. The amount of wasted material overall didn't change with the modifications done to the angling plate, but as with the outflow, the modification to utilize a positioning pole instead of a lead screw greatly reduced the cost. Figure 4.26 below shows the second design of angling plates.

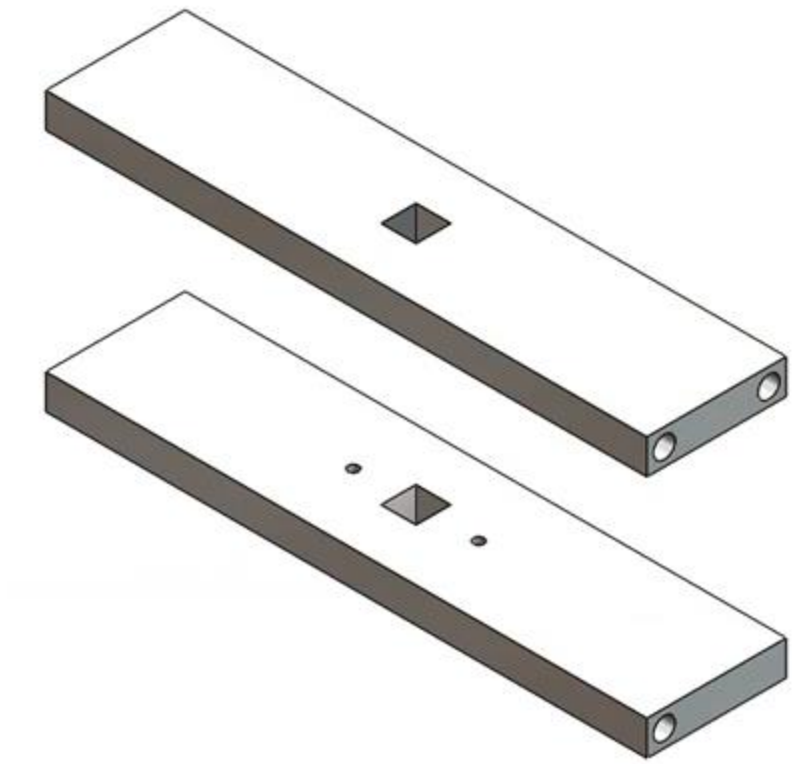

Figure 4.26: Optimized Angling Plates

4.3.5.5 Positioning Rod

The largest alteration that occurred for the outflow overall was the change from utilizing a continuous positioning lead screw for moving the outflow backing with a discretized positioning pole. The pole is made from ½ inch wide aluminum square extrusion clearance holes for #6-32 bolts along the point in ½ inch intervals. A #6-32 bolt, and nut will hold the outflow backing in position based on how far the distance required is. Although the change from a lead screw to a rod increased the machining time substantially for the actual positioning implement, the cost dropped considerably as the lead screw no longer required two mounting nuts and two flanges, which would have been over engineered for the purposes needed anyway. The positioning rod, while discreet, was so much lower in cost that numerous poles at different height intervals could easily be manufactured for low cost. Figure 4.27 below shows the second design positioning rod.

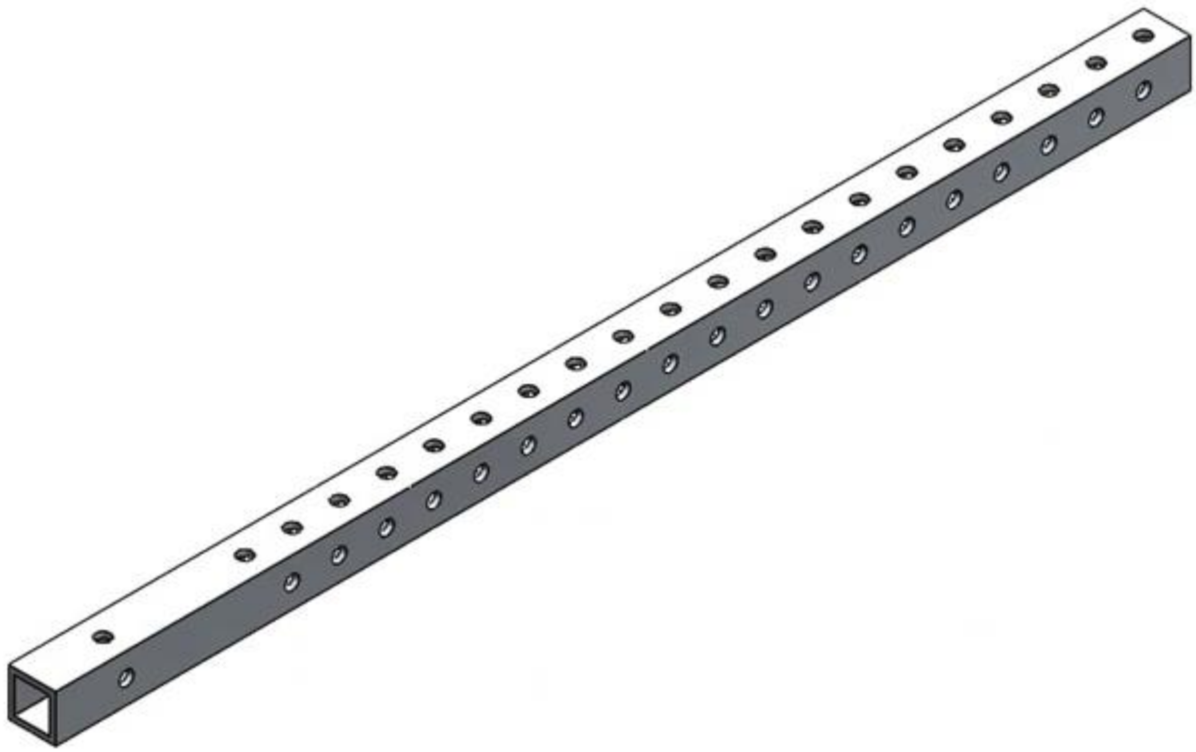

Figure 4.27: Optimized Positioning Rod

Figure 4.28 below shows the completed model for the screen with connections as well as the outflow positioning implements and outflow backing.

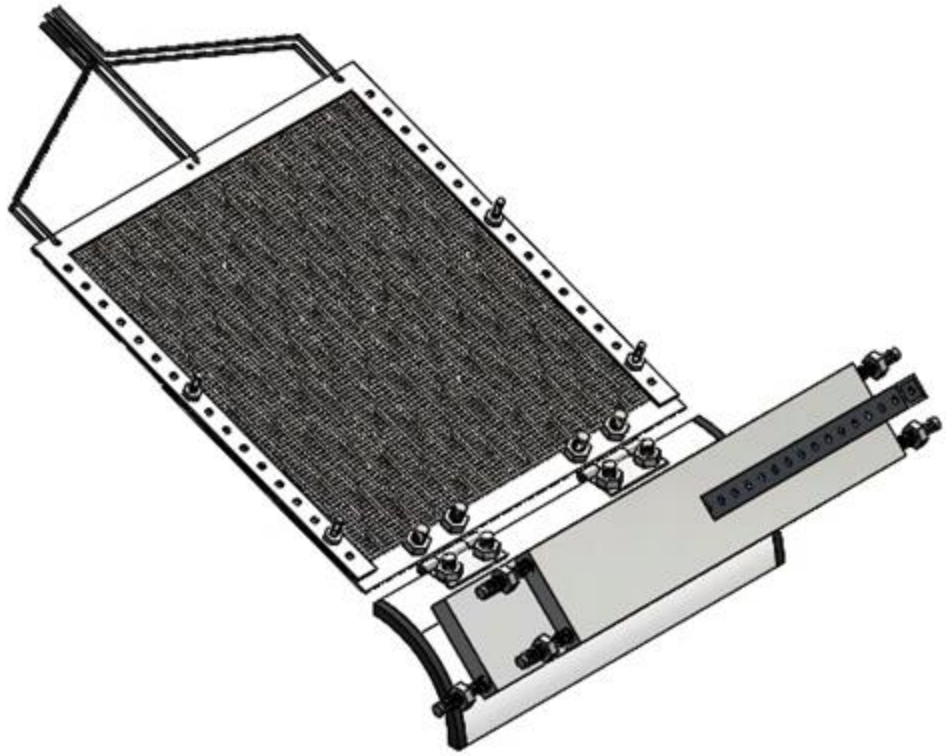

Figure 4.28: Second Design Screen and Outflow Model

4.3.6 Overhang Optimization

4.3.6.1 Aluminum Extrusions

The last major section of optimization was the Overhang and Prony Brake connection. The overhang outlined in Chapter 3 served the purpose of holding the mass set and scale for measuring the output of the Prony brake. The first design utilized one-inch square aluminum t-slot extrusions. A more cost effective 20-20 Series 5 aluminum t-slot extrusion was sourced for minor alterations 20 mm square extrusions with through holes that can be used with M5 bolts. Each component was shortened first to its nearest metric conversion, then each length was further reduced. The overhead truss shape was removed as it was deemed unnecessary. Each of the components that spanned the width of the flume were reduced from 457mm to 450 mm. Each piece that ran along the length of the flume was reduced from 393mm to 250mm.

Additionally, each piece that connected the upper part of the overhang to the lower was reduced from 305mm to 250 mm. These changes helped to reduce the cost and waste needed to construct the overhang considerably. Moreover, the change to metric, made the connecting materials, such as nuts and bolts, more available, further reducing costs. As stated in Chapter 3, the overhang shouldn't experience more force that will cause any components to yield, so the changes made were deemed to be ideal as the parts were overengineered prior to optimization. Figure 4.29 below shows the 4 connecting components for the overhang.

Figure 4.29: Optimized Aluminum Extrusions

4.3.6.2 Scale Rod and Pulley Rod

The next component of the Overhang that was altered were the rods that connected the pulley and scale to the overhang itself. The rods were kept the same ¼ inch diameter and were still made from aluminum. However, the rods were modified to better limit the movement of the components attached to them. First each end of both the Scale Rod and the Pulley Rod had a square of 0.19-inch sides cut down for 1.25 inches. This allows the rod to sit in the machined L bracket without moving. This simple modification to the aluminum rods prevents the data collected from the Prony Brake from being altered. In addition, the Pulley Rod has a 3/16-inch diameter cut into it to allow the pulley sheave with the same diameter to sit snugly on the rod. Figure 4.30 below shows the Scale Rod and Pulley Rod.

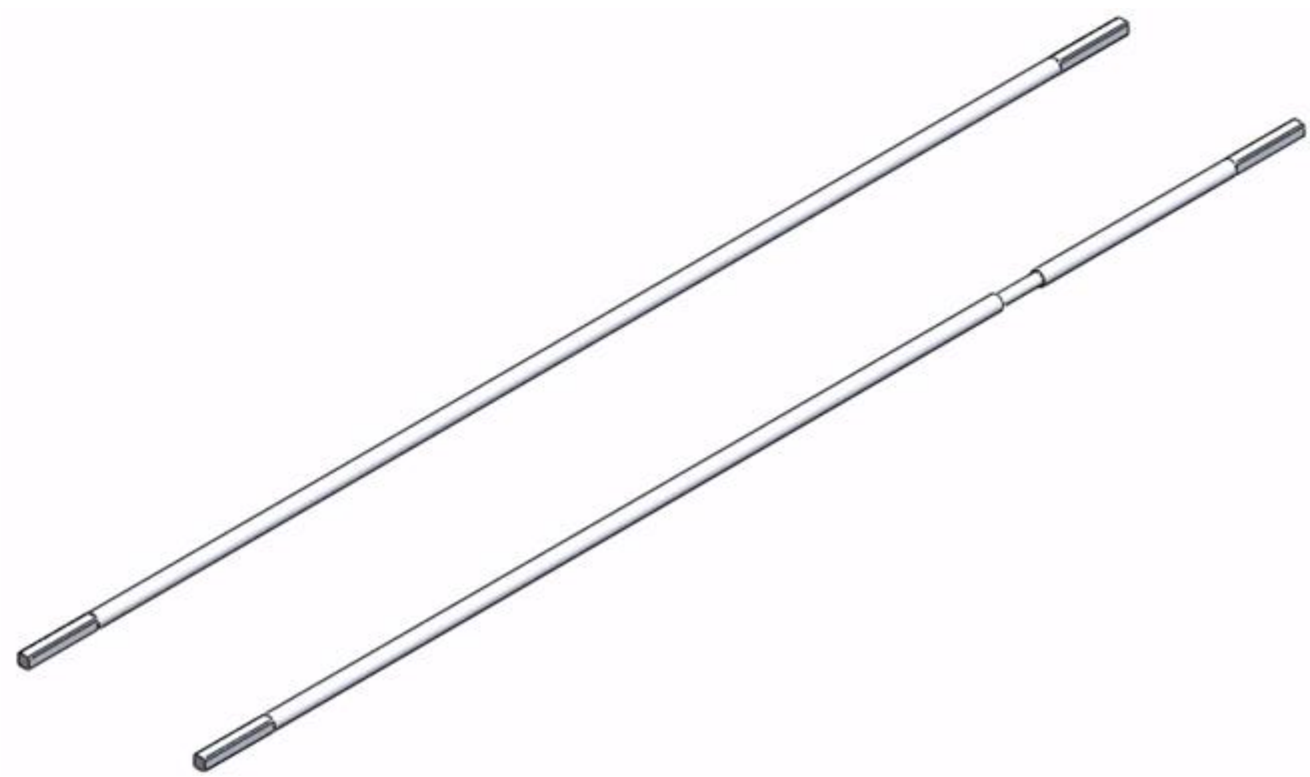

Figure 4.30: Optimized Aluminum Rods- Scale and Pulley

4.3.6.3 L Bracket

The last modification made to the Overhang optimization was the alteration of the 20-20 Series 5 aluminum L brackets. The L bracket remains the exact same except for one leg the M5 clearance hole is drilled over with a square clearance hole that allows the Pulley Rod or Scale Rod to sit in the L Bracket without rotating. This simple modification allowed for an improvement in the fidelity of Power and Torque data. Figure 4.31 below shows the second design Overhang L Bracket.

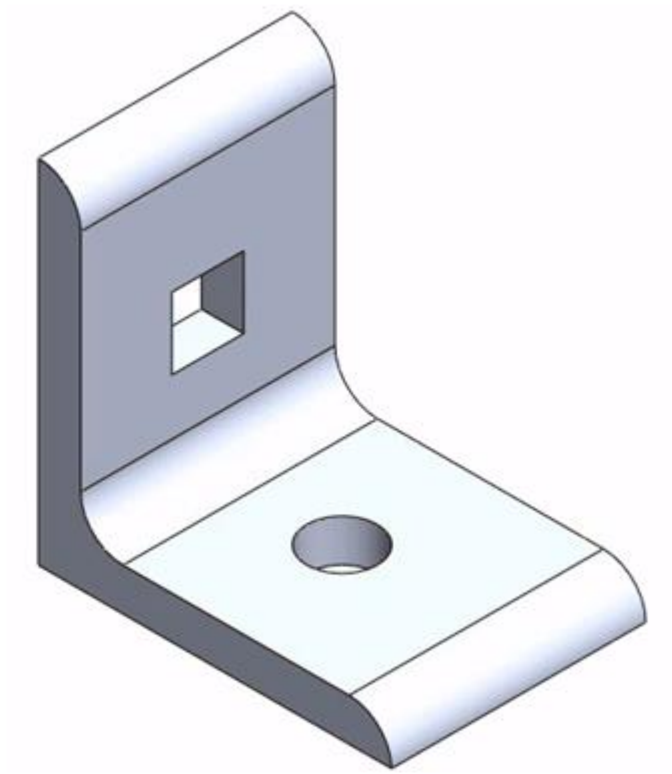

Figure 4.31: Optimized Overhang L- Bracket

Figure 4.32 below shows the fully assembled Overhang and Prony Brake connection following the optimization process.

Figure 4.32: Second Design Overhang Model

With all components completed, and each section assembled, the full assembly of the testing rig was modeled. Figure 4.33 below shows the fully assembled testing rig following optimization.

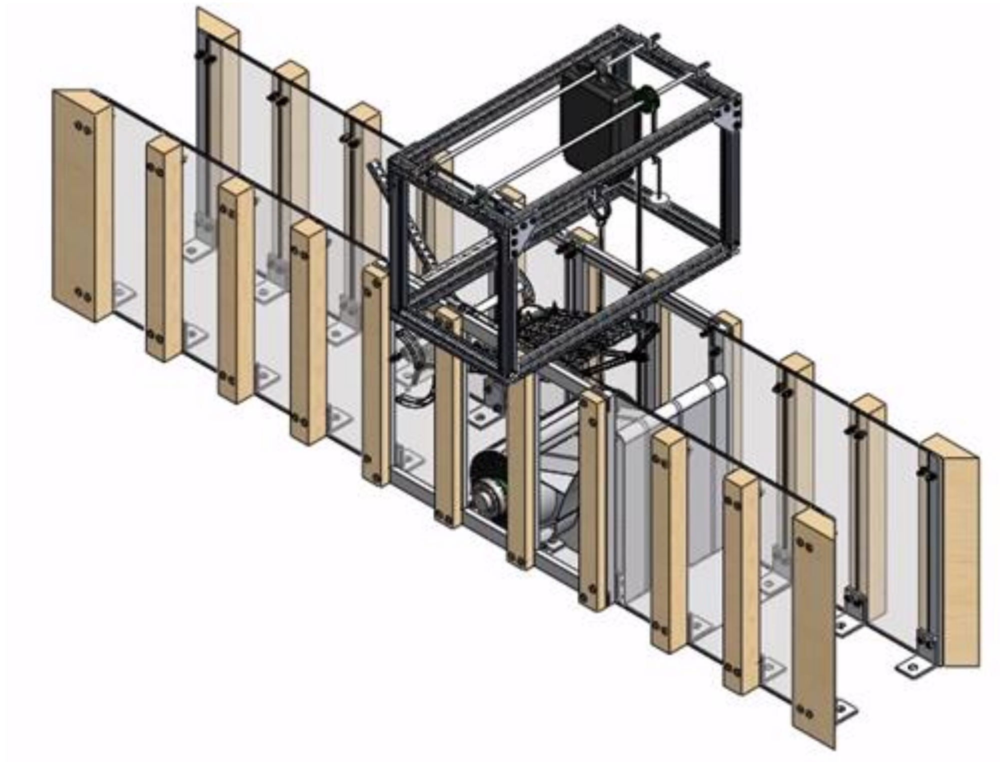

Figure 4.33: Second Design Testing Rig Assembly

Chapter 5

Machining and Construction Anticipatory and Assembly instructions/ Installation Instructions

Chapter 5 will outline all the sourcing and cost of materials for the testing rig as well as tips on manufacturing the testing rig and how to assemble the testing rig.

5.1: Sourcing of Materials and Budget

The materials were ultimately selected based on price as well as quality. Each section of the testing rig was broken down into specific parts and the following section shows costs associated with each component as well as what components to buy and from where. Table 5.1below shows the cost associated with the diversion components for the testing rig.

Table 5.1: Sourcing for Diversion

Item	Unit Cost	No. Required	Total Cost	Supplier	Purchase Specifics
Viewing Panels	$4.09	14	$57.26	estreetplastics	3/16" Thick Acrylic 6" Wide 18" Long
Wooden Support Buttresses	$3.48	2	$6.96	Lowe's	2 by 2 Lumber 8' Length
Wooden Corner Support	$3.98	1	$3.98	Lowe's	2 by 4 Lumber 8' Length
Aluminum Support	$12.01	1	$12.01	Get Metals	3/16" Thick 6061 Al 1" Wide 6' Long

The total cost associated with the Diversion after optimization was $80.21. This was a $74.32 reduction from the projected cost of the first design of $154.53. This is equivalent to a Diversion cost reduction of 48.09%.

Table 5.2 below shows the costs associated with casing components of the testing rig.

Table 5.2: Sourcing for Casing

Item	Unit Cost	No. Required	Total Cost	Supplier	Purchase Specifics
Angling Panel	$9.79	2	$19.58	estreetplastics	.5" Thick Acrylic 6" Wide 18" Long
Turbine Panel	$9.79	2	$19.58	estreetplastics	.5" Thick Acrylic 6" Wide 18" Long
Viewing Panel	$9.79	2	$19.58	estreetplastics	.5" Thick Acrylic 6" Wide 18" Long
Wooden Support Buttress	$1.78	2	$3.56	Lowe's	1 by 2 Lumber 8' Long
Aluminum Brace A	$36.28	1	$36.28	Get Metals	.5" Thick 6061 1" Wide 8' Long
Aluminum Brace B	$45.98	1	$45.98	Get Metals	.5" Thick 6061 1.5" Wide 6' Long
Aluminum Brace C	$67.72	1	$67.72	Get Metals	.75" Thick 6061 1.5" Wide 6' Long
Lip Seal	$7.90	2	$15.80	Amazon	30mm
Ball Bearings	$11.20	2	$22.40	Grainger	30mm ID

The total cost of the casing components of the testing rig, following optimization was $250.48. This optimization resulted in an increased cost of $20.79 from the first design Casing cost in Chapter 3 of $229.69. Although the cost of the casing components increased by 9.05% after optimization, the rigidity of the material and increased visibility was deemed worthwhile as this modest cost increase helped to reduce the cost greatly in the Diversion.

Table 5.3 below outlines the costs of each component associated with Inflow and Weir following the optimization process.

Table 5.3: Sourcing for Inflow & Weir

Item	Unit Cost	No. Required	Total Cost	Supplier	Purchase Specifics
Weir A	$21.90	1	$21.90	Metalliferous	12" by 24 " Gauge 20 3003 Al
Weir B	$9.95	1	$9.95	Metalliferous	12" by 12" Gauge 20 3003 Al
Weir C	$9.95	1	$9.95	Metalliferous	12" by 12" Gauge 20 3003 Al
Weir Back Connection	$9.95	1	$9.95	Metalliferous	12" by 12" Gauge 20 3003 Al
Weir Supports	$20.00	2	$40.00	Piedmont Plastics	1/4" Thick 12" Long 24" Wide HDPE
Backflow Inhibitor	$21.90	1	$21.90	Metalliferous	12" by 24" Gauge 20 3003 Al
Angling Cap	$9.95	1	$9.95	Metalliferous	12" by 24" Gauge 20 3003 Al
Weir Seals	$3.91	1	$3.91	Amazon	1.88" Wide 30' Duct Tape
Weir Lifts	$23.30	1	$23.30	Amazon	12" x 6" x 4" Block Polyurethane Foam Carving

The total cost following optimization for the Inflow and Weir was $150.81. This showed a decreased cost of $35.97 from the $186.78 cost for the Inflow and Weir outlined in Chapter 3. This alteration reduced the cost of the Inflow and Weir by 19.26%.

Table 5.4 below outlines the costs associated with the Outflow and Screen components following optimization.

Table 5.4: Sourcing for Outflow & Screen

Item	Unit Cost	No. Required	Total Cost	Supplier	Purchase Specifics
Flow Backing	$10.27	1	$10.27	Home Depot	Schedule 40 4" PVC Pipe
Positioning All Thread	$1.58	3	$4.74	Home Depot	1/4" Wide 12" Long Zinc Threaded Rod
Angling Plates	$24.36	1	$24.36	Get Metals	.5" Thick 2" Wide 2' Long 6061 Al
Screen Hinge	$0.59	2	$1.18	Zoro	1 3/8" W x 1 1/2" H Zinc plated Door and Butt Hinge #G3453633
Positioning Pipe	$3.69	1	$3.69	Online Metals	0.5" x 0.063" Al Square Tube 2' 6063-T52 Extruded #20685
Positioning Braces	$0.26	4	$1.04	Zoro	Brace, Corner 1" #4PB60
Flow Backing Gasketing	$1.68	1	$1.68	Global Industrial	4" EPDM Short Shank Gasket #WGB553179
Diversion Screen	$6.35	1	$6.35	Online Metals	.5" Hole x 16 Ga. Al Expanded 3003- Flattened #22511
Positioning Rope	$5.48	1	$5.48	Lowes	.125" x 48' Braided Nylon Rope Item # 1289799
Screen Hold A	$7.50	1	$7.50	Metalliferous	6" by 12" Gauge 14 3003 Al
Screen Hold B	$13.90	1	$13.90	Metalliferous	12" by 12" Gauge 14 3003 Al

The total cost associated with Outflow and Screen components following optimization is $80.46. This represents a saving of $153.65 from the Outflow and Screen components total outlined in Chapter 3 of $234.11. Overall, the alterations in the Outflow and Weir components resulted in a cost decrease of 65.63%. Table 5.5 below outlines the costs associated with the Overhang and Prony brake connection following optimization.

Table 5.5: Sourcing for Overhang

Item	Unit Cost	No. Required	Total Cost	Supplier	Purchase Specifics
Prony Scale	$304.53	1	$304.53	McMaster	Legal-For-Trade 15 lb Capacity
Weight Set	$15.95	1	$15.95	Home Science Tools	Slotted 250 Grams
Prony Rope	$5.95	1	$5.95	Amazon	Cotton Braided 3/16" Thick 150'
Friction Wheel	$5.95	1	$5.95	E-Rigging	3/16" Cable 2" Dia. Sheave
Connection Pulley	$7.21	1	$7.21	Grainger	1/4" Max Cable 1 1/8" Out. Dia
Aluminum Extrusions	$42.44	1	$42.44	MISUMI	20x20 5-Series KHFSB5-2020 4000 mm
T Nuts	$0.64	20	$12.80	MISUMI	Pre-Assembly HFS5 Short Nuts
M5 Bolts	$9.78	1	$9.78	Fastenere	M5-0.8 x 10mm Button Head (100 pk)
L Brackets	$0.35	4	$1.40	Alibaba	2020 Al. 6063 L Shaped Slotted Bracket
Joining Plate	$9.99	1	$9.99	Amazon	Boeray 2020 series Al Joining Plate (4 pk)
Aluminum Rod	$2.78	1	$2.78	Online Metals	.25" Al Round Bar 4' 6061-T6511

The total cost associated with the Overhang and Prony Brake after optimization is $418.78. This represents a cost reduction of $37.06 from the first design Overhang cost of

$455.84 in Chapter 3. This resulted in a cost decrease of 8.13%. Table 5.6 below outlines the costs associated with miscellaneous components following the optimization process.

Table 5.6: Sourcing for Miscellaneous

Item	Unit Cost	No. Required	Total Cost	Supplier	Purchase Specifics
Al Footer	$24.12	1	$24.12	onlinemetals.com	2"x2" .1875" t Al Angle 3'
Diversion Bolts	$15.61	2	$31.22	Grainger	1/4"-20 Coarse 2" (50 pk)
Diversion Nuts	$3.62	1	$3.62	Grainger	1/4"-20 Hex Nut (100 pk)
Flume Floor Bolts	$7.00	1	$7.00	Fastenere	1/4"-20 Flat Head Socket 1/2" (25 pk)
Backflow Bolts	$7.00	1	$7.00	Fastenere	1/4"-20 Button Head Socket 5/8" (25 pk)
Positioning Bolts	$7.00	1	$7.00	Fastenere	#6-32 Button Head Socket 3/4" (50 pk)
Number 6 nuts	$2.89	1	$2.89	Grainger	#6-32 Hex Nut (100 pk)

The total cost associated with miscellaneous components following optimization is $82.85. This is a cost reduction of $8.85 from the total cost of miscellaneous components of $91.70 from Chapter 3. This represents a reduction of 9.65% in cost. Table 5.7 below outlines the total cost of each component after optimization as well as the cost savings and percentage of cost saved.

Table 5.7: Second Design Cost Breakdown

Section	Cost	% Of Total	Cost Saving	% Saved
Diversion	$80.21	7.54%	$74.32	48.09%
Casing	$250.48	23.55%	-$20.79	-9.05%
Other	$82.85	7.79%	$8.85	9.65%
Inflow/Weir	$150.81	14.18%	$35.97	19.26%
Outflows	$80.46	7.56%	$153.65	65.63%
Hanger	$418.78	39.37%	$37.06	8.13%
Total	$1,063.59	100.00%	$289.06	21.37%

The total cost of the testing rig following optimization is $1,063.59. Compared to the total cost of $1,352.65 associated with the testing rig in Chapter 3, the optimization resulted in a projected $289.06 in savings or a 21.37% reduction in cost. Overall, the largest area of savings was the Outflow components which resulted in a cost reduction of $153.65. Please note that all of the components stated to be purchased in the tables above are from outside vendors. Further cost savings could be achieved by working with suppliers that work directly with Ohio State.

5.2: Machining Instructions

With all components purchased, the machining of individual components can begin. Section 5.2 will lay out the general outlines and notes needed to manufacture the different sections of the testing rig.

5.2.1 Diversion

The construction of the diversion itself will be made up of several parts. To begin, the walls of the diversion should be created first. The acrylic plate called for in Chapter 4 should be cut down to 15 inches long from their 18-inch initial dimensions. This step is not necessary if time and resources are limited. Each of the 3/16 thick acrylic panels will then have a ¼-20-inch diameter clearance hole drilled into the corners. Figure A1in Appendix A shows the SolidWorks drawing associated with the wall of the diversion.

Next, the wood buttress supports should be cut from the two by two, eight-foot-long boards. Each board will be cut into five 15-inch-long sections with roughly 21 inches of scrap lumber per board. Each 15-inch section will have four ¼-20 clearance holes drilled through them. Counter bore the four holes on one side about 3/16 of an inch deep using a drill bit of ½ inch diameter. Figure A2 in Appendix A shows the SolidWorks drawing associated with the wooden buttress for the diversion.

To create the wood end supports, cut the two by four board mentioned in Chapter 4 into four, 15-inch-long segments. This will leave roughly 21 inches of lumber for scrap. Use an angling saw to cut a 45 degree angle the thickness of the board terminating at one corner of the board. Using the shortened side of the board with the angle cut out, drill four ¼-20 clearance through holes in the board. Flip the board over and counter bore each through hole roughly 3/16 inch deep using a ½ inch diameter drill bit. Lastly, apply a coat of lacquer or apply duct tape to the angled edge of the board to prevent water seepage. Figure A3 in Appendix A shows the SolidWorks drawing associated with the Wooden End Buttress for the diversion.

For the aluminum end supports, measure and mark a 15-inch section in the bar. Cut using a horizontal band saw. Repeat this procedure until you have four roughly 15-inch sections. This will leave roughly one foot of scrap. For 45-degree angle utilize the 45-angle gage block to machine a precision cut. Figure A4 in Appendix A shows the SolidWorks drawing associated with the Aluminum End Supports.

Any locations that have the connection of bolts to other components for the testing rig should be followed to at least the hundredths place for tolerances. Other dimensions such as height and width are not as important, therefore tolerances to the tenth of an inch should be adequate.

5.2.2 Casing

The casing is created using panels, supports, braces, and fasteners. The casing panels are created from ½ inch thick acrylic sheets. Like the diversion panels, three inches from the 18-inch-long acrylic should be removed. Each of the 6 panels will have four ¼-20 clearances through holes drilled in each corner of the acrylic. For the two turbine holding panels, drill a 30mm through hole. For the angling panel, drill a ¼-20 clearance hole for one of the all threads. Surround this hole with the two 90-degree annuli that will act as the positioning holes for the angling plates themselves. Figures A5, A6, and A7 in Appendix A show the SolidWorks drawings associated with the Casing Viewing Panel, the Casing Turbine Panel, and the Casing Angling Panel, respectively. The width of all holes should be no greater than 5/16 inch in diameter as the annuli and the through hole need to utilize a ¼-20 nut that holds the angling plates in position.

For the buttresses that support the casing, cut the eight-foot section of one by two into 15-inch sections. This should leave roughly 21 inches of scrap lumber. Of the buttresses two are designed for the outer part of the casing. They have four ¼-20 clearance holes drilled through the lumber. Each of these holes will have a ½ inch diameter counterbore drilled 3/16 of an inch deep on one side. Figure A8 and A9 in Appendix A show the outer wood buttresses for the casing.

One of the wood sections is designed for the central buttresses of the casing. These 15-inch-long sections of one by two will have four ¼-20 clearance holes drilled through them. Each hole will be drilled through the wood ⅜ inches from either 15-inch-long side. One side will also be counterbored with a ½ inch diameter drill bit a depth of 3/16 inch. Figure A10 in Appendix A shows the drawing associated with the central casing wood buttresses.

For Casing Brace A, cut the eight foot long section of one inch wide ½ inch thick aluminum into 19.5 inch long sections using a horizontal band saw. This should yield roughly 18 inches of scrap aluminum. Mill one long face down to 7/16 of an inch in thickness, as close as possible with regards to tolerance. Mill 2 identical rectangles six inches on center from each of the previous two millings. Lastly, drill six holes through the aluminum in the depressions, each one being ¼-20 clearance holes. Figure A11 in Appendix A shows the drawing associated with the Casing Brace A. The thickness of the bar and the depressions can be machined to the tenths place with regards to tolerance, however, the positioning of the holes is critical, therefore, utilize a tolerance to a hundredth of an inch.

For Casing Brace B, cut the six-foot-long section of the 1.5 inch wide, ½ inch thick aluminum into 15-inch-long sections using a horizontal band saw. This will yield roughly one foot of aluminum waste. Like Casing Brace A, mill down one face to 7/16 of an inch in thickness with an accuracy of two decimal places. Use the end mill to mill down 7/32 of an inch to an accuracy of 2 decimals one inch from the ends. The end depressions in Casing Brace B will fit as a lap joint with the depressions in Casing Brace A, therefore, follow the same level of tolerance with both components for the depressions so that a tight fit will occur. Figure A12 in Appendix A shows this.

For Casing Brace C, cut and square the six-foot-long section of the 1.5 inch wide, ¾ inch thick aluminum the same way as Casing Brace B. Mill two depressions one inch in from either end of each bar 7/32 of an inch to an accuracy of two decimal places. These are the same style depressions as in Casing Brace B, therefore make sure the tolerance is the same for both Casing

Brace B and Casing Brace C. On the other 15 inch long by 1.5-inch-wide side mill down 5/16 of an inch to 2 decimal places for 15 inch long by ¾ inch wide. Lastly drill four ¼-20 clearance holes through the aluminum bar. The positioning of the holes is critical, therefore machine to a precision of 3 decimal places. Figure A13 in Appendix A shows the SolidWorks drawing for Casing Brace C.

5.2.3 Weir

The weir will be constructed using 3 separate sections of Gauge 20 3003 Alloy Aluminum. Weir section A will require the manufacturer to bend a 90 degree turn in the metal followed by a hem at the end. Weir B will be curved in two separate locations to form the foot hold for the weir. Weir section C will be bent along an 18-inch radius to ensure that the ogee weir shape is kept. For Weir Section A the machinist should mark the 12 by 24 piece of aluminum to reduce it in size to 8.625 inches by 19 inches, Weir section B will be reduced in size to 10.5 by 8.625 inches from the 12 by 12 piece and Weir section C will be reduced from the 12 by 12 piece to 9.5 by 8.625 inches. Figures A14, A15, and A16 in Appendix A show the exact dimensions associated with machining the sheet metal to form the weir. Cut the metal to the needed size using the vertical bandsaw. Debur as necessary. The exact width of the weir metal should be as close to the width of the channel between the diversion walls as possible to the tenth of an inch. After cutting the metal, place the ¼-20 clearance through holes in Weir section A and Weir Section B at 0.85 inches in and 1 inch in from the edges respectively. These holes are needed to keep the weir in place by anchoring it to the flume floor therefore it is important that they are spaced 3 inches apart. The positioning of these holes is crucial therefore, machine to a tolerance of one hundredth of an inch. After the metal of the weir is machined, the creator will need to cut the weir plastic supports to the specifications outlined in Figure A17 in

Appendix A. The supports will be made from 0.25-inch-thick HDPE to ensure rigidity of the weir. The exact tolerances of the plastic are not as crucial, so long as the supports fit snugly within the metal weir pieces when assembled. Sandpaper may be implemented toward the end of the cutting process to get a better fit where necessary.

5.2.4 Inflows

The inflows will be manufactured in much the same way as the weir. Each metal piece of the inflow will be made from 20 Gauge 3003 Alloy aluminum. Subsequently the inflows require HDPE supports that closely match the shape. Figures A18, A20, and A22 in Appendix A show the aluminum inflow shapes. Figures A19, A21, and A23in Appendix A show the plastic supports that fit within the metal inflows. As with the weir, the exact tolerance is not as critical, except for the positioning holes that will connect the inflow to the flume floor. The metal should be cut in length to the tenths place regarding tolerances.

5.2.5 Other

For the L-brackets along the floor of the flume, take the three-foot section of aluminum L beam extrusion and mark 1.5-inch sections for the length of the bar. Cut the aluminum L Beam first using the horizontal band saw to separate the parts into more easily maneuverable pieces, every five or six markings, then proceed to get more precise cuts with the vertical band saw. With each 1.5-inch section cut for each of the L-brackets, square the outer faces of the L bracket. Debur as necessary. 14 of the 22 L brackets are for the main diversion. Of the 22, four will be for the Central part of the Casing. Of the 22, two will be outer Casing L Brackets A and two will be outer Casing L brackets B. The diversion L Brackets, as well as Casing Brackets A and B are similar in that after squaring, the machinist need only drill two through holes in one leg either 0.5 inches or 1.5 inches from the corner and ⅜ of an inch away from either side of the L bracket.

Then drill a ¼-20 clearance hole through the center of the other face at 1.3125 from the edge. The clearance hole drilled that will be parallel to the floor of the flume will be countersunk with an angle of 82 degrees to direct the flat head socket bolts to the flume anchor positions. The exact width of the L brackets is not critical so a tolerance to the tenths place should suffice. The positioning of the holes for the bolts, for the casing, diversion, and flume are important to ensure connections occur, therefore, follow tolerances to the hundredth of an inch. Figures A24, A25, and A26 in Appendix A show the drawings for the Casing L Bracket A, Casing L Bracket B, and Diversion L Brackets respectively. The four Central Casing L brackets require the machinist to shorten one leg from 2 inches to 0.6 inches, and the other from 2 inches to 1.7 inches so they can fit under the weir. Furthermore, the machinist will have to chamfer the corners of the upright portion of the L bracket and mill out a 0.1-inch section of the lower leg to accommodate for the nut in the L bracket connection. Figure A27 in Appendix A shows the central casing L brackets. The Central Casing L Brackets length and width are not critical, so tolerances to the tenths place is acceptable. Again though, the positioning of the bolt holes is critical which requires a tolerance to the hundredths place.

5.2.6 Outflows

To create the Rear Angling Plate and the Front Angling Plate, first cut the two-inch wide ½ inch thick aluminum bar to a length of 8.675 inches each using a horizontal band saw. The length of the bar is not critical so tolerances to the tenths place is acceptable. The Rear Angling Plate will have two ¼-20 clearance holes drilled through the length of them and the Front Angling Plate will have one drilled through the length. These holes are designed to accommodate the ¼-20 all thread. The straightness of these holes is more important than the actual clearance diameter, therefore, utilize whatever means necessary to ensure straightness.

The position of these through holes are vital so that they do not interfere with the square clearance hole, therefore tolerance to the hundredths place is ideal. The Front Angling Plate will have a ½ inch square clearance hole drilled in the center that will hold the positioning pole, which is a ½ inch square aluminum extrusion, therefore, the clearance hole should be slightly larger than ½ inch to hold the pole snuggly. Two #6-32 clearance holes will be drilled through the Front Angling Plate on either side of the square clearance hole. These will hold the positioning braces mentioned in Section 5.1, so match the distance of the #6-32 holes to the distance of the holes in the positioning brace if they were to lie flat against the Front Angling Plate. Figure A27 and A28 in Appendix A show the SolidWorks drawings for the Rear and Front Angling Plates, respectively.

For the Gasketing, take the gasket and cut into four equal length quarters. Adhere two together and adhere to the Outflow Backing. Repeat this process with the other two pieces of gasketing. Figure A29 in Appendix A shows the SolidWorks drawings for the Outflow Gasketing.

For the Outflow Backing take the PVC pipe and cut it along to the 8.25-inch length. Next, cut the PVC into four equal length quarters. Using a belt sander shave a flat portion into the back portion of the PVC pipe that is at least 0.3 inches wide that runs the length of the PVC quarter. Use the flat surface as a datum to drill the two #6-32 clearances through holes. Create a series of drill holes to create the depression for the ½ inch square aluminum extrusion to sit in. Use the belt sander to sand out sections on the edges of the quarter for the button head screws. Drill the four ¼-20 clearance holes in these locations. Sand down the inside section here for the button head screws as well as the interior curvature. Dimensions here are only benchmarks for rough sizing. Compare the distances needed for bolt hole locations to the Positioning Braces and the hinges connecting the Screen Assembly to the Outflow Backing. The manufacturer should wear a breathing apparatus, as the chemicals in PVC can be detrimental if inhaled. Figure A31 in Appendix A shows the SolidWorks drawing for the Outflow Backing.

For the Positioning Pole, a foot long section will be cut from the two-foot long ½ inch square aluminum extrusion. A series of #6-32 clearance through holes will be drilled in the Positioning Pole. The hole that is shown as ¾ inch in from one side should be altered in position to match the height of the corresponding hole in the Positioning Brace assuming that it is lying flat against the Outflow Backing. Furthermore, the next hole in the Positioning Pole should be drilled to line up with the Positioning Brace assuming that the minimum distance between the Outflow Backing and the Front Angling Plate is utilized. After that the #6-32 clearance through holes should be drilled at ½ inch apart from each other. The positioning of these holes is crucial, so make sure that the tolerances are to the hundredths place. The two through holes that correspond to the Positioning Braces should be at the exact same height on the other two faces of the Positioning Pole. Then drill holes ½ inches apart on this side, but at an additional ¼ inch distance following the second hole so that the positioning pole can be used at quarter inch increments. Figure A32 in Appendix A shows the SolidWorks drawing associated with the Positioning Pole.

5.2.7 Screen

For the screen assembly first take the twelve inches by six-inch Gauge 14 Aluminum Sheet Metal and cut out the U shape into one piece to form Screen Hold A and cut the U shape into the piece of twelve inch by twelve inch Gauge 14 Aluminum sheet form Screen Hold B. Dimensions here are not crucial, so tolerancing to the tenths place is fine. Next, drill a series of #6-32 clearance holes in each according to the drawings. The positioning of the two plates is crucial, so ensure that the holes on Screen Hold A will line up with Screen Hold B when placed edge to edge. Drill the ¼-20 clearance holes in through Screen Hold A to allow for the connection to the hinge. Verify the distances of the hinge prior to drilling these holes. Figures A33 and A34 in Appendix A show the SolidWorks drawings for Screen Hold A and B respectively. Although not shown in Appendix A, the other two parts of the Screen Assembly need to be manufactured. Cut the Screen called for in Section 5.1 to the desired width and length. Lastly, cut three pieces of twine that will be fed through the 0.1-inch holes in Screen Hold B. These hole sizes can be altered to the nearest drill size that can accommodate the twine purchased. The location of these holes is not critical, as the twine sits in them to pull the Screen Assembly to the angle desired via tension.

5.2.8 Overhang

The Overhang assembly consists mainly of 20-20 Series 5 Aluminum Extrusions. First cut the Aluminum extrusion along the 0.5-meter point using the horizontal bandsaw. Create two equal length 250mm long sections using the vertical band saw. Drill two clearance through holes for M5 bolts. Tap both ends to a depth of 10mm such that they can be fitted with M5 bolts. This will form the Overhang Top Width Connection which is shown in Figure A35 in Appendix A. Repeat this procedure without tapping the ends to create the four components of Overhang Lower Width Connection. These components are shown in Figure A36 in Appendix A. Cut another one-meter piece of 20-20 Series 5 Aluminum using the horizontal bandsaw and cut this into four equal length 250 mm long sections using the vertical band saw. Tap both ends of each piece to a depth of 10mm in the same manner as the Overhang Top Width Connection. This will form the four Riser Connections shown in Figure A37 in Appendix A. Use the remaining two-meter section of 20-20 Series 5 Aluminum Extrusion to cut four equal length 450mm long pieces. Again, tap each side to a depth of 10mm such that a M5 bolt could be fitted to them. Figure A38 in Appendix A shows the drawing for the Flume Length Connection.

Following the machining of all Overhang connection components, take the 20-20 Series 5 L bracket and machine out a five-millimeter square over the predrilled hole in one leg. Figure A39 in Appendix A shows the Overhang L Bracket. Lastly, the Pulley Rod and Scale Rod must be machined. Each rod must be cut to a length of 20 inches. Each end of each rod will have a 0.15-inch square cut into each end for 1.25 inches. These ends will sit in the L Bracket of the overhang. The pulley rod will have an additional turned cut in it that will allow for the rod to hold the pulley called for in 5.1 snugly in place. Confirm the diameter of the pulley and connection cuts needed prior to making any alteration. Figures A40 and A41 in Appendix A show the Pulley Rod and Scale Rod SolidWorks drawings accordingly.

5.3 Assembly

With the necessary machining complete, the manufacturer will be ready to move on to assembling each section of the testing rig.

5.3.1 Diversion Assembly

The diversion should be broken into two main parts, assembly, and installation. Moreover, the diversion should be assembled in four sections: The front left, the front right, the back left and the back right. Lay the wooden end support on a flat surface with the counterbore side face down. Next lay the wooden buttresses on the flat surface with the edges parallel to the end support, with the counterbore side face down. Insert the ¼-20 hex bolts so that the head lays flush with the back of the wooden support and sits in the counterbore, a sizable amount of the bolt should be sticking out the other side. With the supports laid down on the surface, with the top bolts placed in their holes, attach the aluminum support so that the 45-degree angle is collinear with the 45-degree angle of the end wooden support, placing the aluminum top hole over the bolt. Attach the four 3/16-inch-thick acrylic panels over each of the bolts sticking out of the top, each panel should be six inches wide and sit flush with one another. Attach these panels and the aluminum support to the wooden support using the ¼-20 nuts. Next slide the wooden supports, still the counterbore side face down over the edge of the table and insert the bottom row of hex bolts so they lay flush against the back wooden supports. Feed the bolt through the predrilled holes in the acrylic and aluminum. Then place the four L Brackets over the bolts so that the countersunk wide is pointing parallel over the acrylic panels. Attach the ¼-20 nuts to the L brackets. Repeat this procedure for the other three configurations of the diversion. Two sections will have three panels and two sections will have four panels. Do not connect the front and rear sections of the diversion. Figure B1 in Appendix B shows the assembly of one portion of the diversion.

5.3.2 Casing Assembly

The casing will be assembled next, using the ½ inch thick viewing panel, the turbine holding panel, and the angling panel. Lay the end wooden buttress A, made of the 15 inch long two by one board, down on a flat surface with the counterbore face toward the table surface. Lay two of the central wooden buttresses parallel to end buttress A with end buttress B following this, so that all are lying with the counterbore face touching the table. Feed the top row of hex bolts through the clearance holes and move the wood back onto the table so that the wood bolts do not fall out. Rotate the wooden supports 180 degrees so that the bottom row of holes are near the edge of the table with the counterbore face touching the table. Feed in the bottom row of bolts so they lie flush with the back wooden support and push the wooden supports back onto the table surface to prevent any bolts from falling out. Lay both A Braces over the wooden supports, feeding it through the six bolt holes. Brace A should have the flat side, with no depressions, touching the wooden supports. Next attach the two Brace B's and two Brace Cs into the depressions in Brace A, with the two Brace B being placed in the middle and Brace Cs on the outer depressions, feeding the bolts through the predrilled holes. Lay the acrylic over the braces, nestling the angling panel, the turbine panel, and the viewing panel in. Attach the top row of the ¼-20 nuts. Attach the L brackets to the front of the acrylic, feeding the A L bracket over the bolts that go through the A wooden buttress, the B L bracket over the bolts for the B wooden buttress, and central L brackets over the central buttresses. The countersunk face should run parallel and facing the acrylic panels. Attach the ¼-20 nuts to secure the acrylic and brace to the wooden supports. Repeat this procedure for the other side of the casing, making sure that the panels line up with each other if the counterbore sides of the wooden buttresses are flipped. The through holes in the end wooden buttresses for the casing should line up with the through holes in the 3/16-inch-thick acrylic sheets that make the diversion panels. Figure B2 in Appendix B shows the exploded view for the Casing Assembly.

5.3.3 Weir Assembly

Following the machining of Weir Sections, A, B, and C as well as the machining of the Weir plastic supports, the experimenter will move one to assembly of the weir. The experimenter will first need to weld Weir section A to Weir Section C and then weld Weir section C to Weir Section B. Following the welding, the experimenter will insert the three sections of plastic supports into the Weir Shell, securing them in place using duct tape or a caulk. The three plates should be evenly spaced to ensure a more equal pressure distribution for the water. Figure B3 in Appendix B shows the exploded view of the weir for assembly purposes.

For the construction of the weir sheathing the researcher must take the sheet metal and bend it according to the shape. If this proves too difficult, consider the following method of construction taken from airplane wing construction. Create additional supports that will act to support the polyethylene that touches the floor of the flume. Stretch either canvas or tarpaulin over the supports to create a lightweight alternative solution. For additional waterproofing and stiffening apply a thick lacquer or shellac to create a hardened case over the fabric.

5.3.4 Inflow Assembly

Assembly of the inflow components will be like the assembly of the out weir save for the necessity to weld metal together. The three HDPE pieces associated with each part of the inflow: 20 Degree Top Cap, Backflow Inhibitor, and Weir Connection, will be placed equidistant from each other within the corresponding sheet metal components. These plastic pieces will be attached using either caulk or duct tape. The top cap will be attached to the Backflow inhibitor by using a ¼-20 bolt and nut. The holes of the Backflow Inhibitor, Weir Connection, and Weir will all line up so that when ready to be placed into the flume, the unit can be lowered and anchored to the flume floor using the socket bolts. Figure B4 in Appendix B shows the exploded view of the Inflow and Weir assembly.

5.3.5 Screen Assembly

Assembly of the screen should be completed in three steps. First the screen size selected should be sandwiched between Screen Hold A and Screen Hold B. Feed the four #6-32 0.75-inch bolts through Screen Hold A, the Screen, and Screen Hold B, such that the head of the bolt lays against Screen Hold A. Attach the #6-32 nuts so Screen Hold A is held in place with Screen Hold B. Next, attach the twine to Screen Hold B and braid the three strands together to make a rope of twine. Lastly, use four ¼-20 button top bolts to attach the hinge to Screen Hold A.

Tighten the ¼-20 nuts to the ¼-20 bolts. Figure B5 in Appendix B shows the exploded view of the Screen Assembly.

5.3.6 Outflow Assembly

The outflow should be assembled in five parts. First, adhere the rubber gasketing to the Casing Backflow. Next, attach two of the Positioning Braces over the holes in the rear of the Casing Backflow. Bolt each down using a #6-32 0.75-inch bolt and nut. Attach the other two Positioning Braces to the Near Angling Plate in the same manner. Third, feed the Positioning Pole through the Near Angling Plate square hole and have it sat in the square divot machined out of the Casing Backflow. Use a #6-32 0.75inch bolt and nut to secure the Positioning Pole to the Positioning Braces on either side feeding the bolt through the lowest hole drilled in the Positioning Pole. Choose the distance required between the Casing Backflow and the Near Angling Plate and secure the Positioning Pole to the Near Angling plate in the same manner as was done for connection to the Casing Backflow. Fourth, attach the Screen to the Casing Backflow using four ¼-20 button head bolts and nuts fed through the hinges. Lastly, feed the three all threads through each of the side holes in the Near and Far Angling Plates and feed the Positioning Pole through the square hole in the center of the Rear Angling Plate. Attach the nuts to all thread until ready to assemble the full Rig. Figure B6 in Appendix B shows the exploded view of the Outflow Assembly.

5.3.7 Overhang and Prony Brake Assembly

The assembly of the Overhang and Prony Brake Assembly should be completed in xx steps. First, the two Overhang Lower Width Connections should be attached to the Flume Width Connections using a M5 bolt sitting in the T slot of the Overhang Lower Width Connections. The clearance hole is drilled in these components such that an Allen key can be used to tighten the M5 bolt into the threading of the Flume Width Connections. This will form a rectangle that will sit on the metal lips of the flume. Next, the Riser Connections should be attached to the four corners in the same manner that the Flume Width Connections were connected to the Overhang Lower Width Connections. Third, feed two T nuts into the T-slot of one side of each of the four Riser Connections and four T-nuts into the T-slots of one side of the other two Flume Width Connections. Fourth, lay the two Overhang Top Width Connection pieces such that the threading is parallel with the threading of the T-nuts in the Riser Connections. Feed two T-nuts into each of these components such that the threads of these T-nuts are parallel with the floor. These will allow for the Overhang L Brackets to connect to the Overhang Top Width Connection. Fifth, attach the joining plate to the Overhang Top Width Connections by feeding a M5 bolt through the corner bolt hole the joining plate. Use M5 bolts to attach the joining plate to the Flume Width Connections and Riser connections by tightening the bolts to the T-nuts. Sixth, attach each Overhang L Bracket to the Overhang Width Connection using an M5 bolt. Lastly feed the Pulley rod and Scale Rod through the two L Brackets. Attach the Pulley and Scale Respectively. Feed the rope around the Pulley and friction wheel. Attach the friction wheel to the shaft of the turbine. Figure B7 in Appendix B shows the exploded view of the Overhang and Prony Brake connection.

5.3.8 Full Assembly

For the Full Assembly, attach one side of the casing to one side of the diversion. Feed the three pieces of all thread through the Angling Panel of the Casing, tightening the ¼-20 nut on one side. Feed the Lip seal corresponding to the hole in the Turbine Holding Panel through, having it sit in flush with the inner wall of the diversion that will be exposed to the water. Attach the Ball Bearing to the shaft as well. Feed the three all threads through the side of the other half of the casing. Attach the nuts to keep the angling components in place. Place the Weir and Inflows Assembly under the L Brackets that will hold it in place. Attach the other half of the diversion to the second half of the casing. Attach the friction wheel to the shaft of the turbine with rope attached and lower the entire apparatus into the flume. Attach all bolts to the flume. Lay the Overhang over the lips of the flume.

Chapter 6

Conclusion

6.1: Contribution to Research

The research conducted has provided researchers at The Ohio State University, or at other flume labs globally an ability to improve their testing facilities to better boost fidelity and empirical data gathering to better support the development of small-scale hydropower testing. At the very least this report serves as an artistic representation of the ways in which facilities with a flume could improve the testing of hydrokinetic turbines to act as inspiration for them to improve their own testing capabilities. With the need for cleaner energy intensifying each day, this research will play a role in improving the future capabilities of a sustainable energy world.

6.2: Summary of Research

The research conducted, as outlined in this paper, shows the steps laid out for the development of future systems. The research began with a simple motivation: the necessity to expand renewable energy usage through hydropower and subsequently to improve the research and knowledge around this energy source. This motivation was broken down into a smaller problem noticed by the research community at The Ohio State University: The need to improve the efficiency testing of hydrokinetic turbines at The Ohio State University both to improve our own facilities as well as to reduce transit time of our researchers to another facility. This problem was then solved with a systematic approach as outlined in most product design and development. The specific need was outlined- a testing rig capable of all these different adjustable options was needed. The parameters were set- the cost needs to be x, the size needs to be y, it needs to do z. Initial designs were conceptualized-the ways of raising and lowering, moving the rig, holding the water back, etc. Designs were screened, scored, eliminated, or improved. More intricate modeling of the most prospective designs was conducted. Several design iterations occurred. Modules were assembled into a collective model for holistic understanding. The design was optimized after costs, manufacturing time, and assembly time were considered. A finalized design was ultimately considered. The cost breakdown and sourcing for the materials was given along with this design. Instructions were written as to how the design would be brought to fruition.

6.3: Future Work

Future work could be conducted in three distinct areas. First, future work could be performed to create the design outlined in this paper. Future researchers could take the instructions from this paper to contact suppliers, source materials, manufacture, and assemble this design. Second, future work could be conducted in the improvement of this design to further optimize the design put forth and make modifications more appropriate for the testing desired to be conducted. Third, future work could be conducted to utilize the test rig outlined in this paper to test Williams Cross Flow Turbines.

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Appendices

Appendix A: Drawings for Completed Design

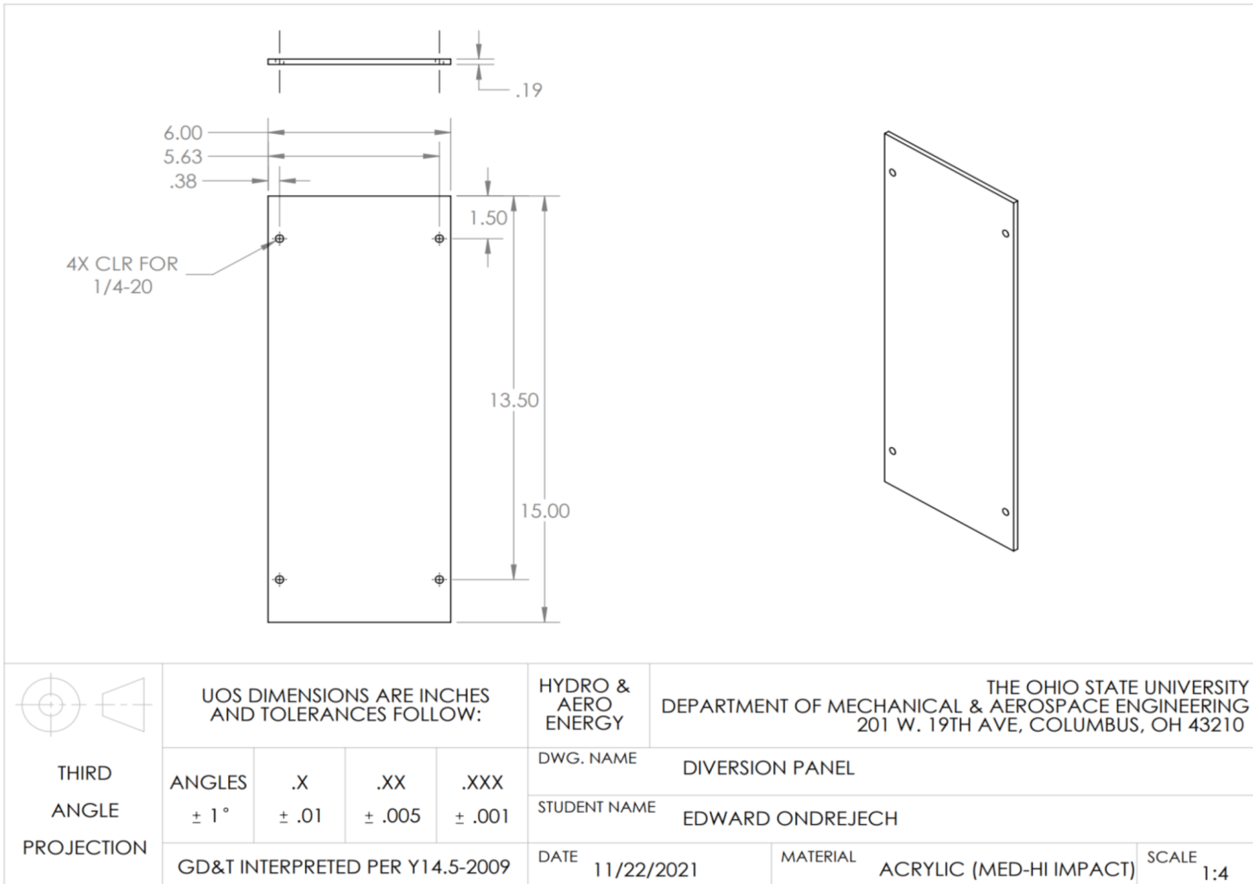


Figure A1: Diversion Walls

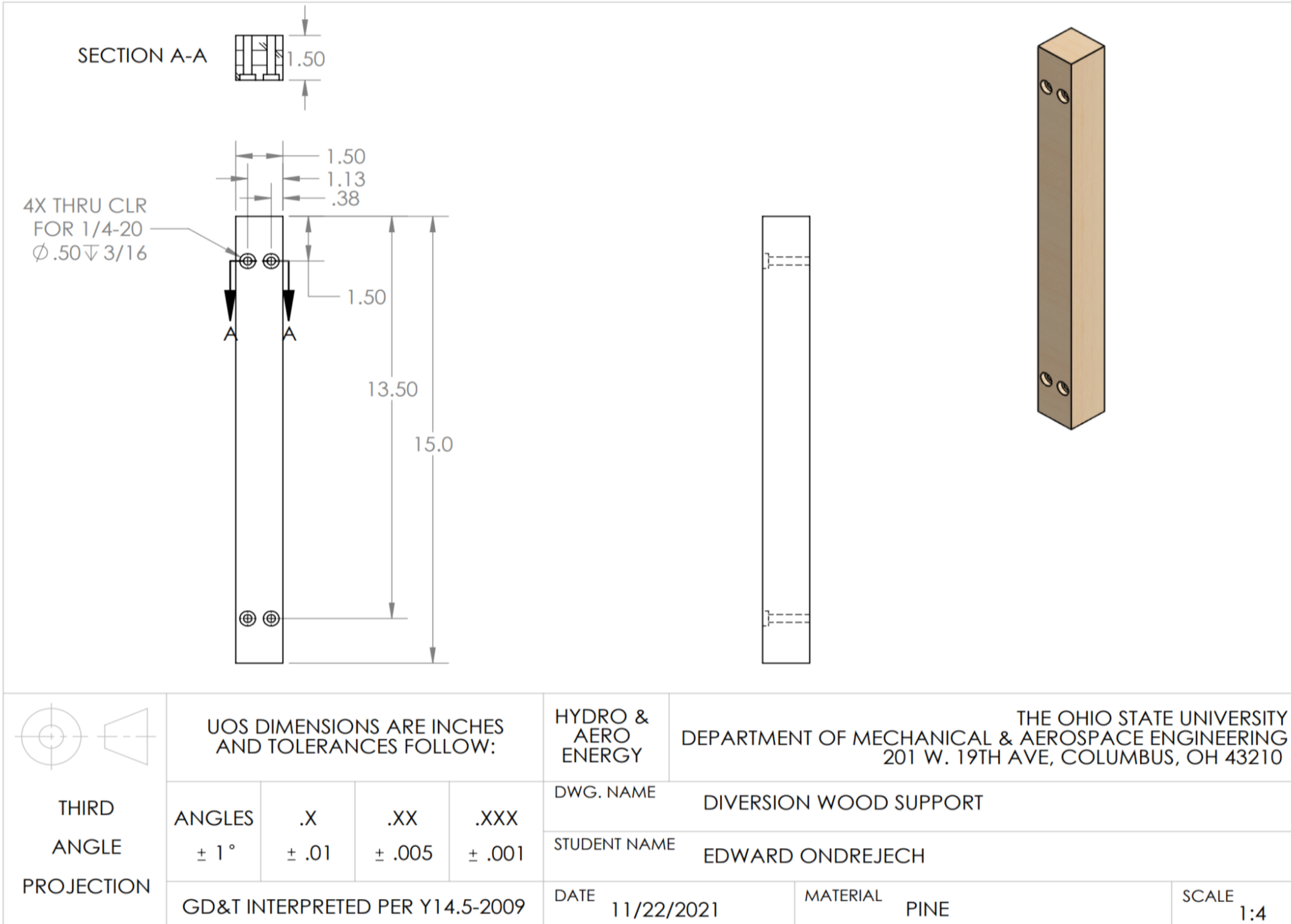


Figure A2: Diversion Wooden Support Buttress

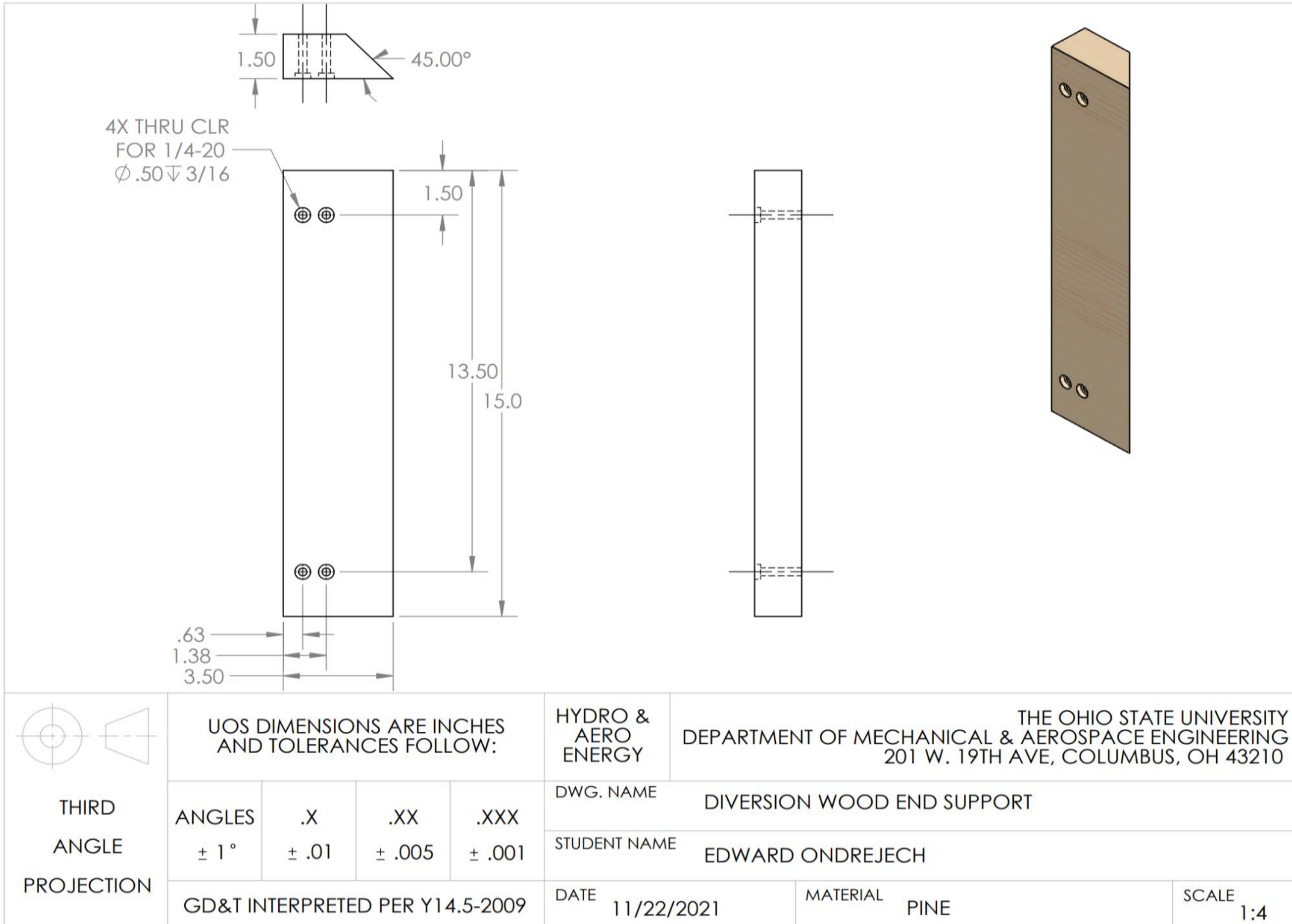
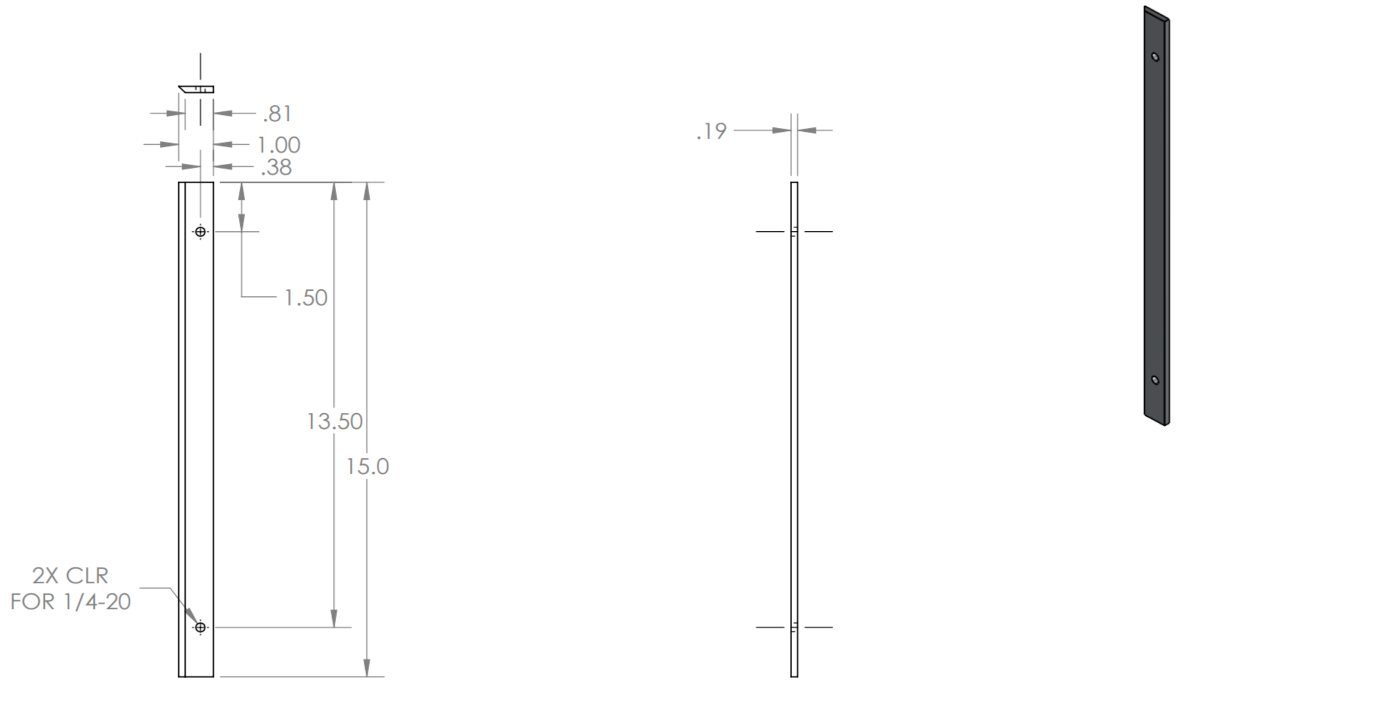


Figure A3: Wooden Corner Buttress



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	ANGLES ± 1°	.X ± .01	.XX ± .005	.XXX ± .001	DWG. NAME	ALUMINUM END SUPPORT
					STUDENT NAME	EDWARD ONDREJECH
	GD&T INTERPRETED PER Y14.5-2009				DATE 11/22/2021	MATERIAL 6061- T6 / SCALE 1:4

Figure A4: Aluminum End Support

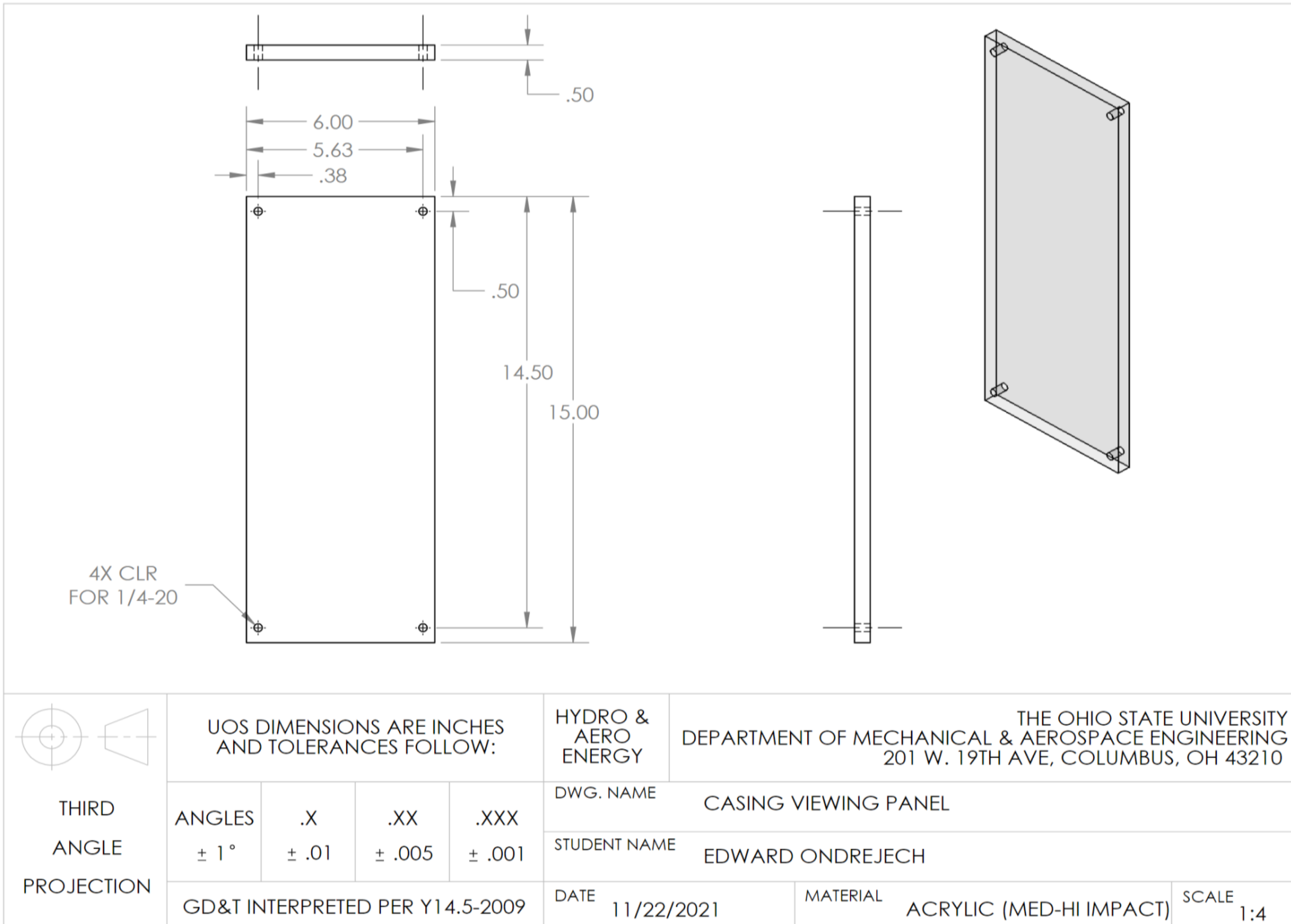


Figure A5: Viewing Panel

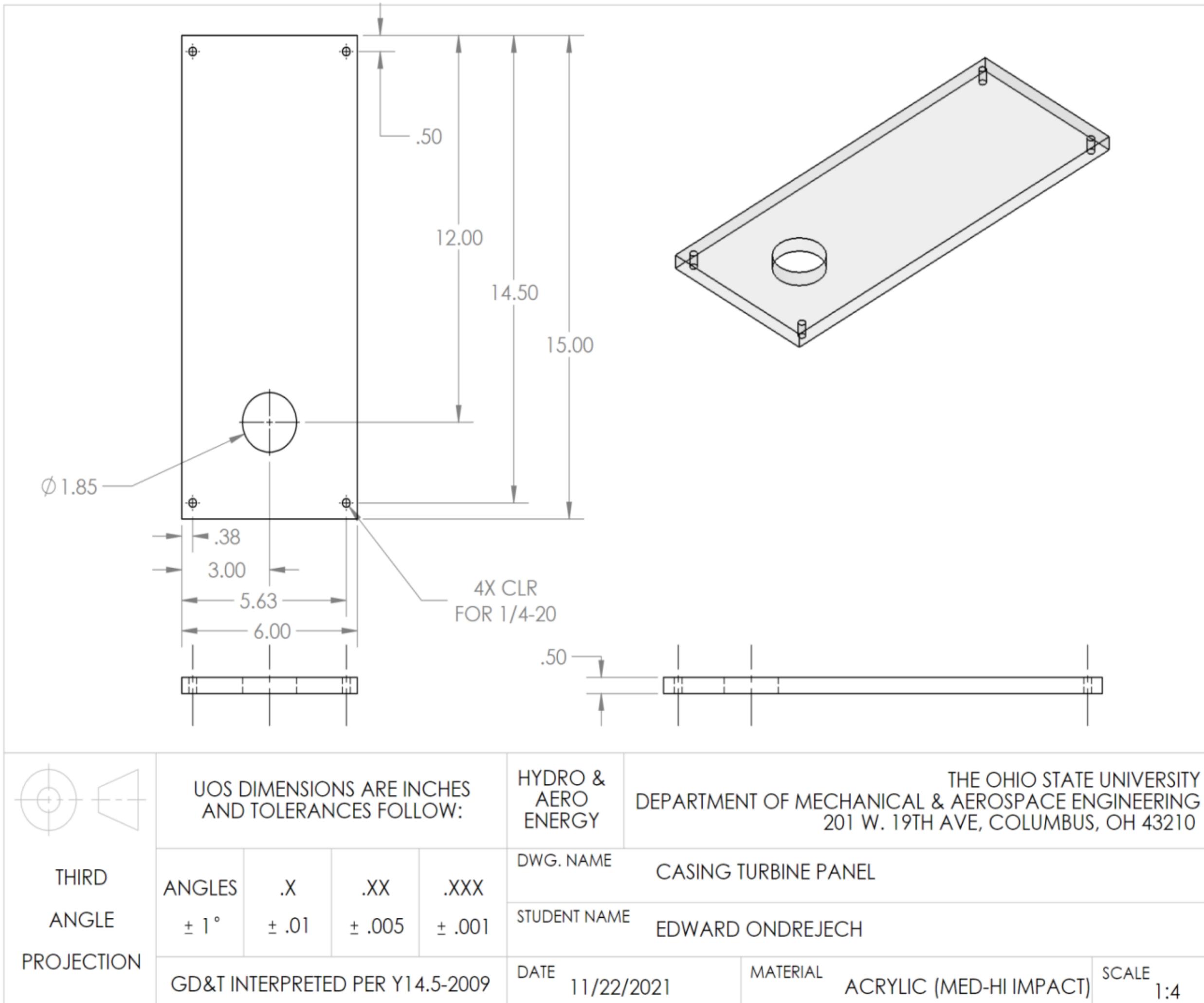


Figure A6: Turbine Connection Panel

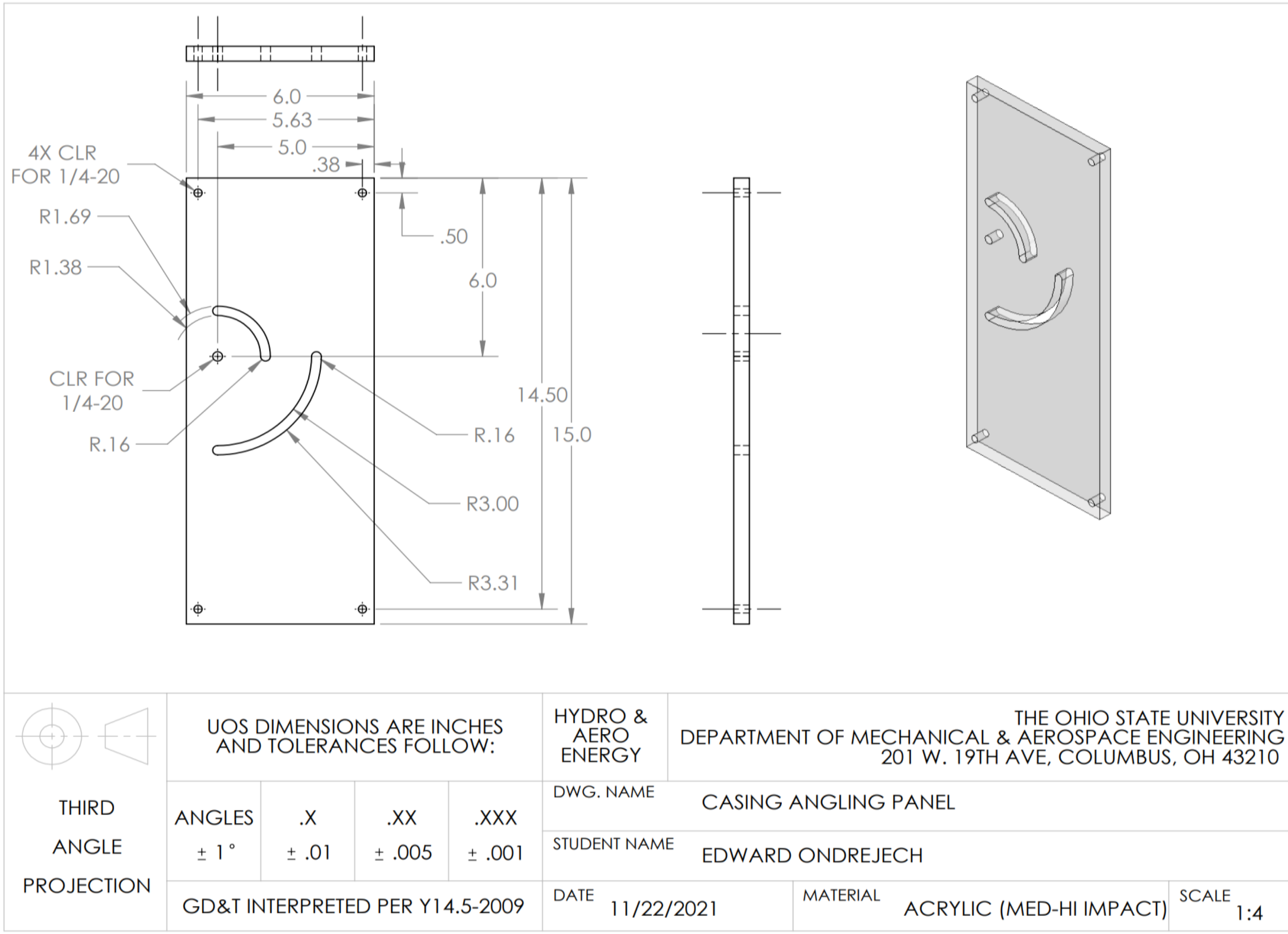


Figure A7: Angling Panel

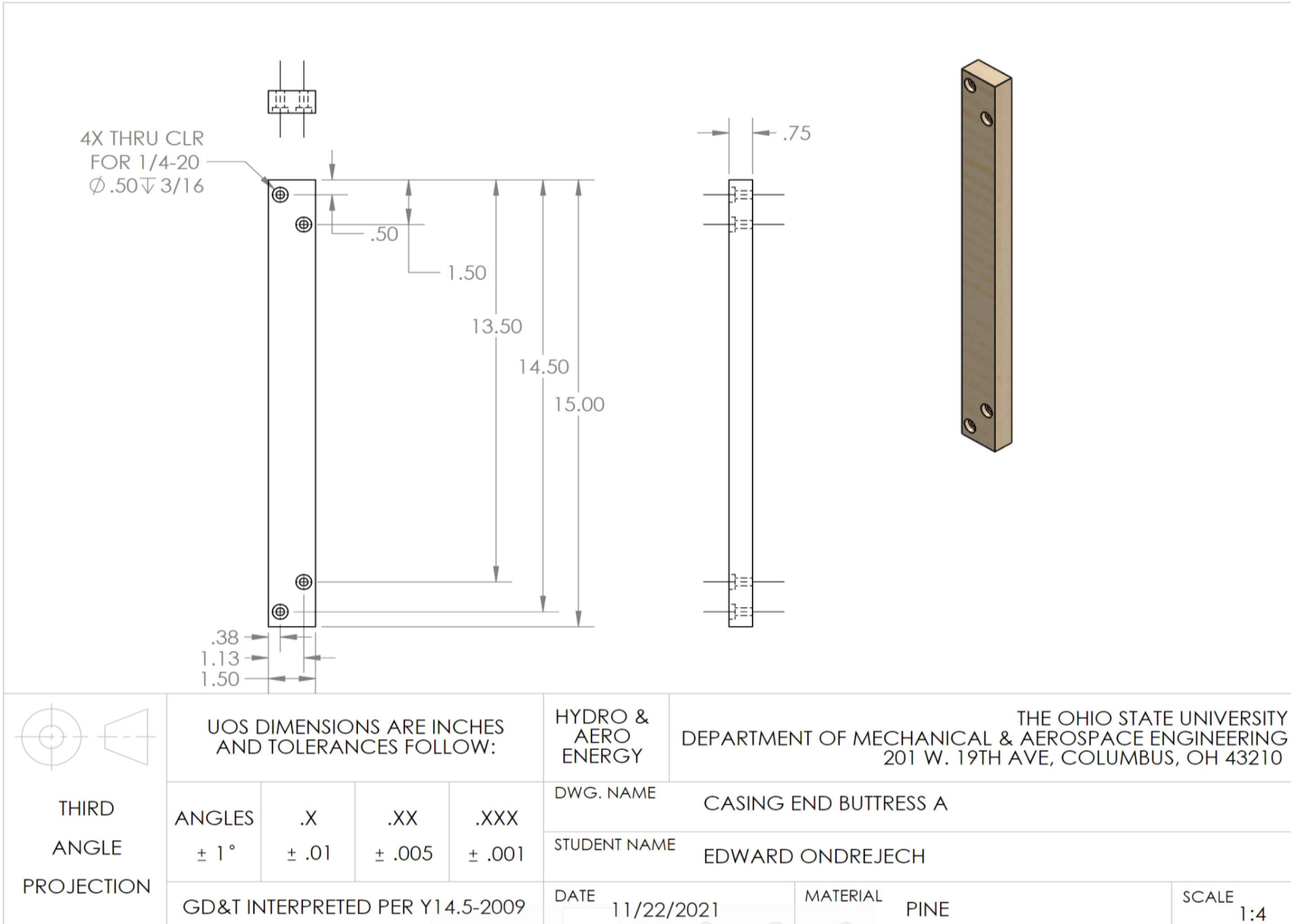
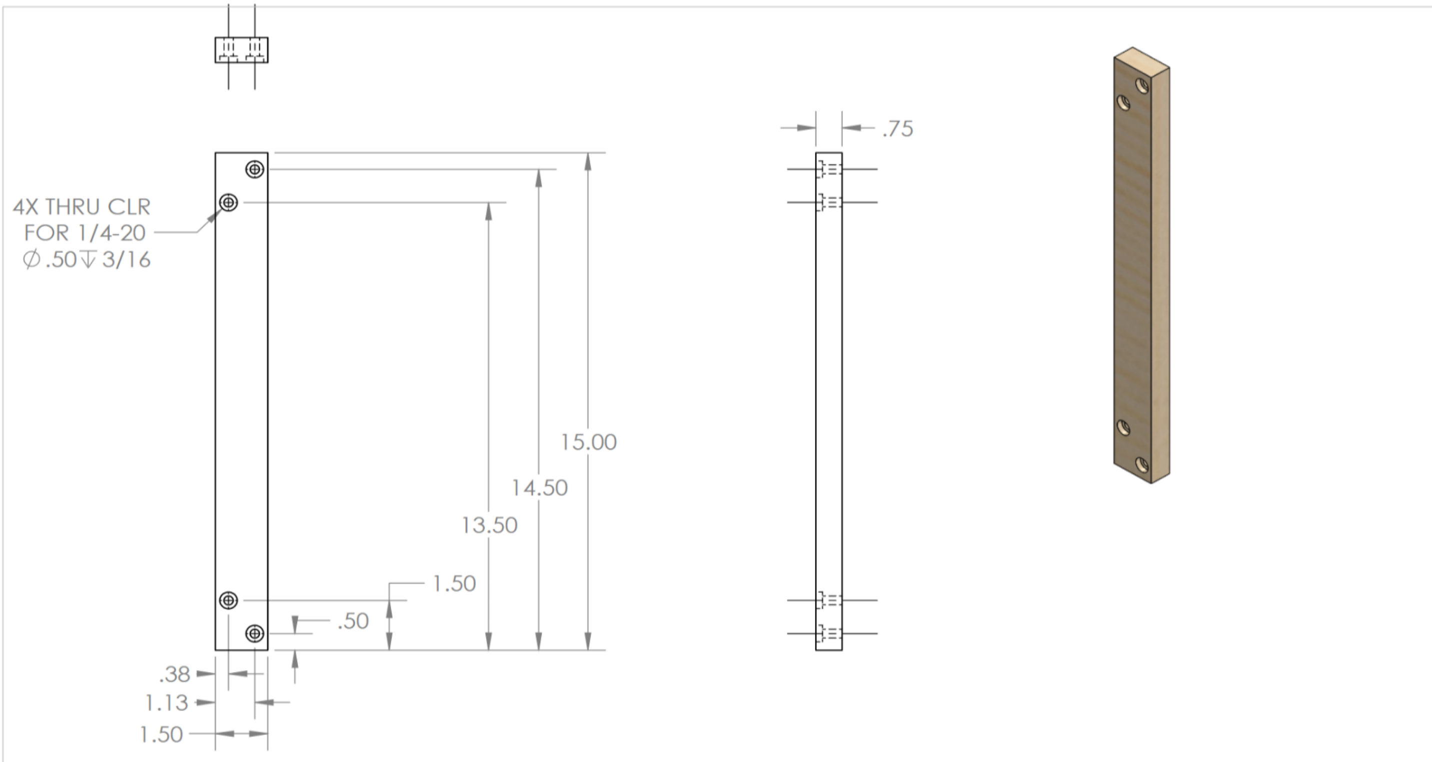


Figure A8: Casing Buttress A



THIRD ANGLE PROJECTION	UOS DIMENSIONS ARE INCHES AND TOLERANCES FOLLOW:				HYDRO & AERO ENERGY — THE OHIO STATE UNIVERSITY DEPARTMENT OF MECHANICAL & AEROSPACE ENGINEERING 201 W. 19TH AVE, COLUMBUS, OH 43210
	ANGLES ± 1°	.X ± .01	.XX ± .005	.XXX ± .001	DWG. NAME CASING END BUTTRESS B
					STUDENT NAME EDWARD ONDREJECH
	GD&T INTERPRETED PER Y14.5-2009				DATE 11/22/2021 — MATERIAL PINE — SCALE 1:4

Figure A9: Casing Buttress B

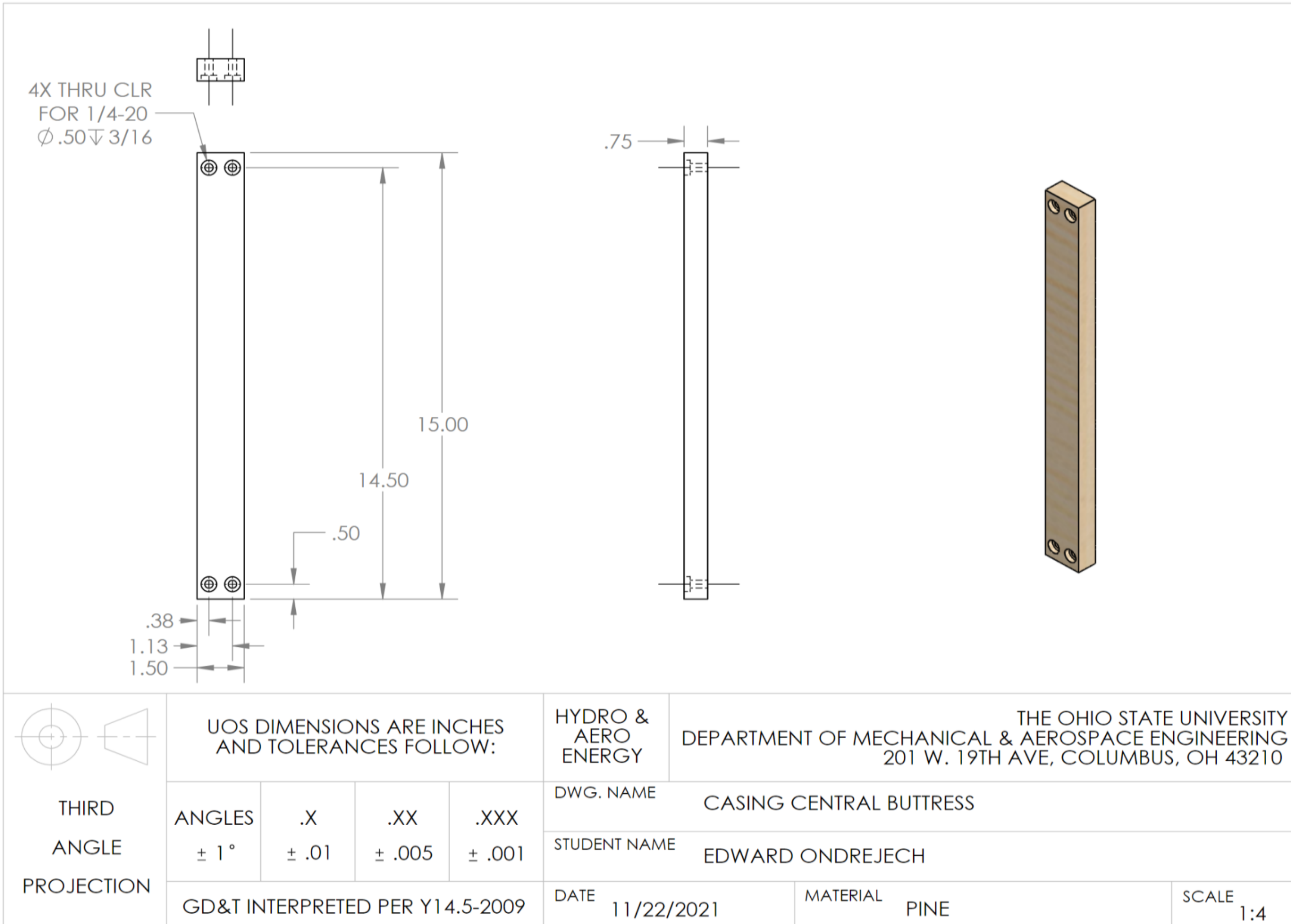
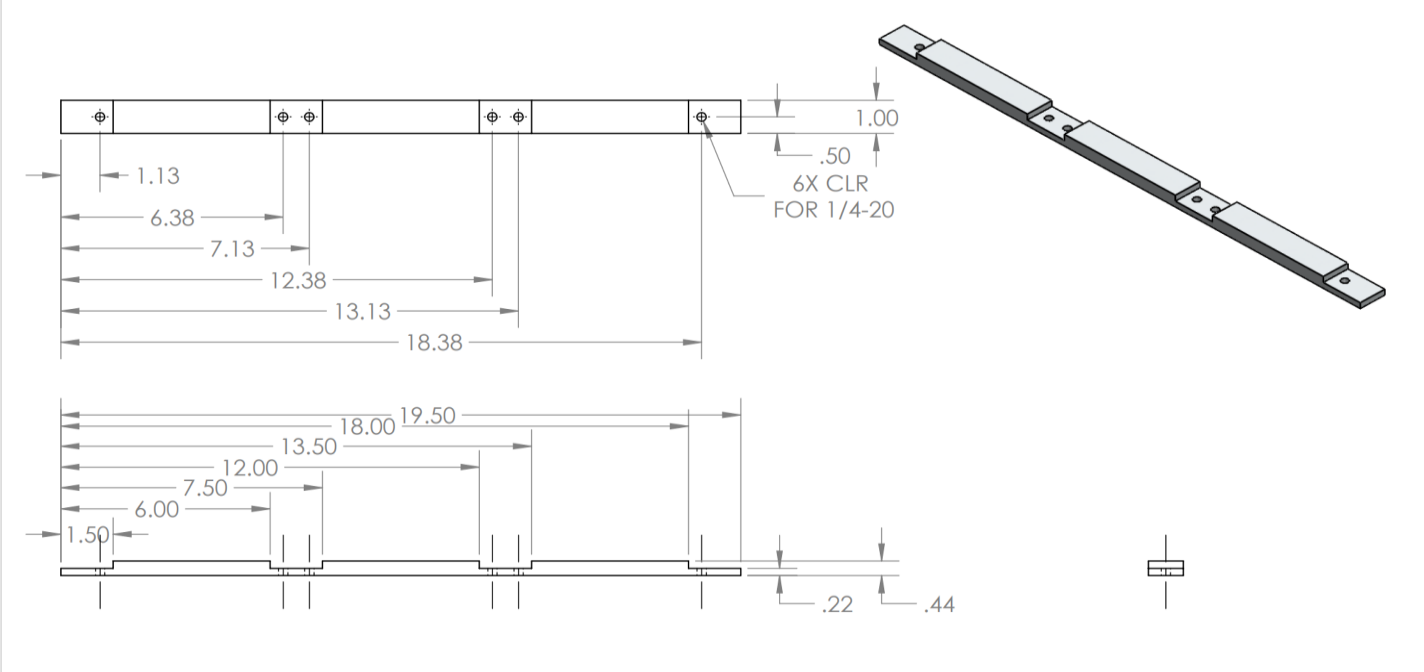


Figure A10: Casing Central Buttress



THIRD ANGLE PROJECTION	UOS DIMENSIONS ARE INCHES AND TOLERANCES FOLLOW:				HYDRO & AERO ENERGY	THE OHIO STATE UNIVERSITY DEPARTMENT OF MECHANICAL & AEROSPACE ENGINEERING 201 W. 19TH AVE, COLUMBUS, OH 43210
	ANGLES ± 1°	.X ± .01	.XX ± .005	.XXX ± .001	DWG. NAME	CASING BRACE A
					STUDENT NAME	EDWARD ONDREJECH
	GD&T INTERPRETED PER Y14.5-2009				DATE 11/22/2021	MATERIAL 6061- T6 SCALE 1:4

Figure A11: Casing Brace A

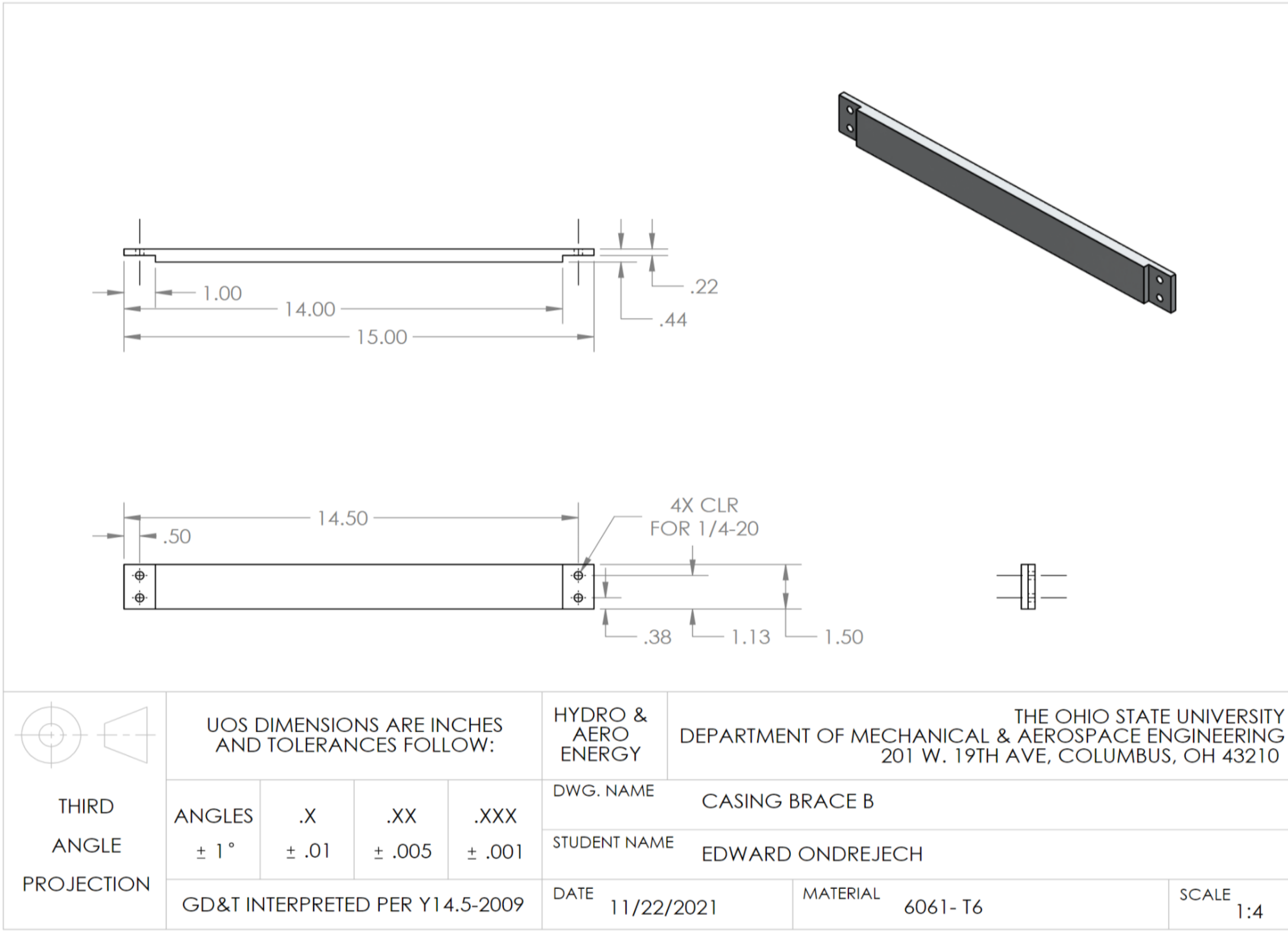


Figure A12: Casing Brace B

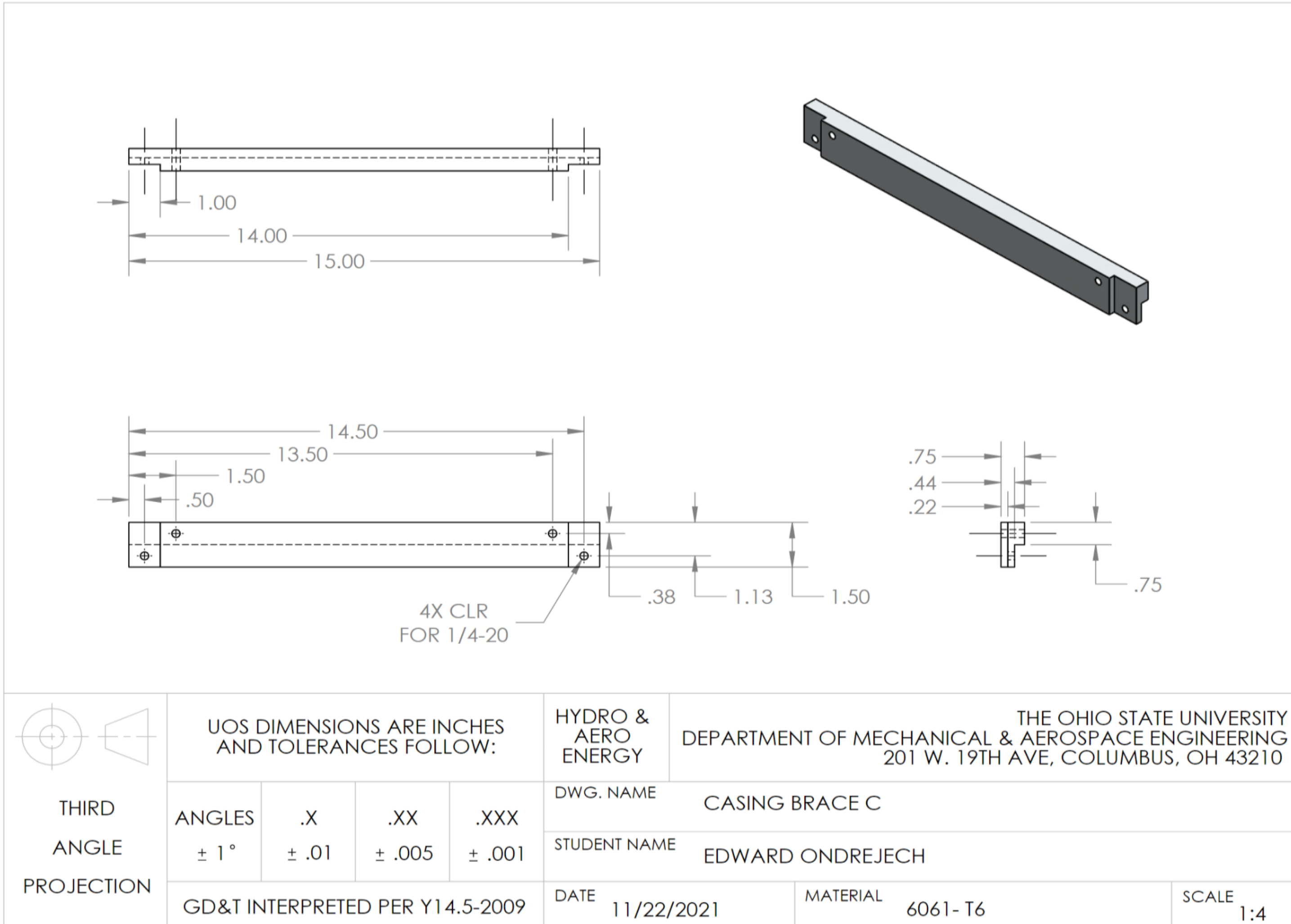


Figure A13: Casing Brace C

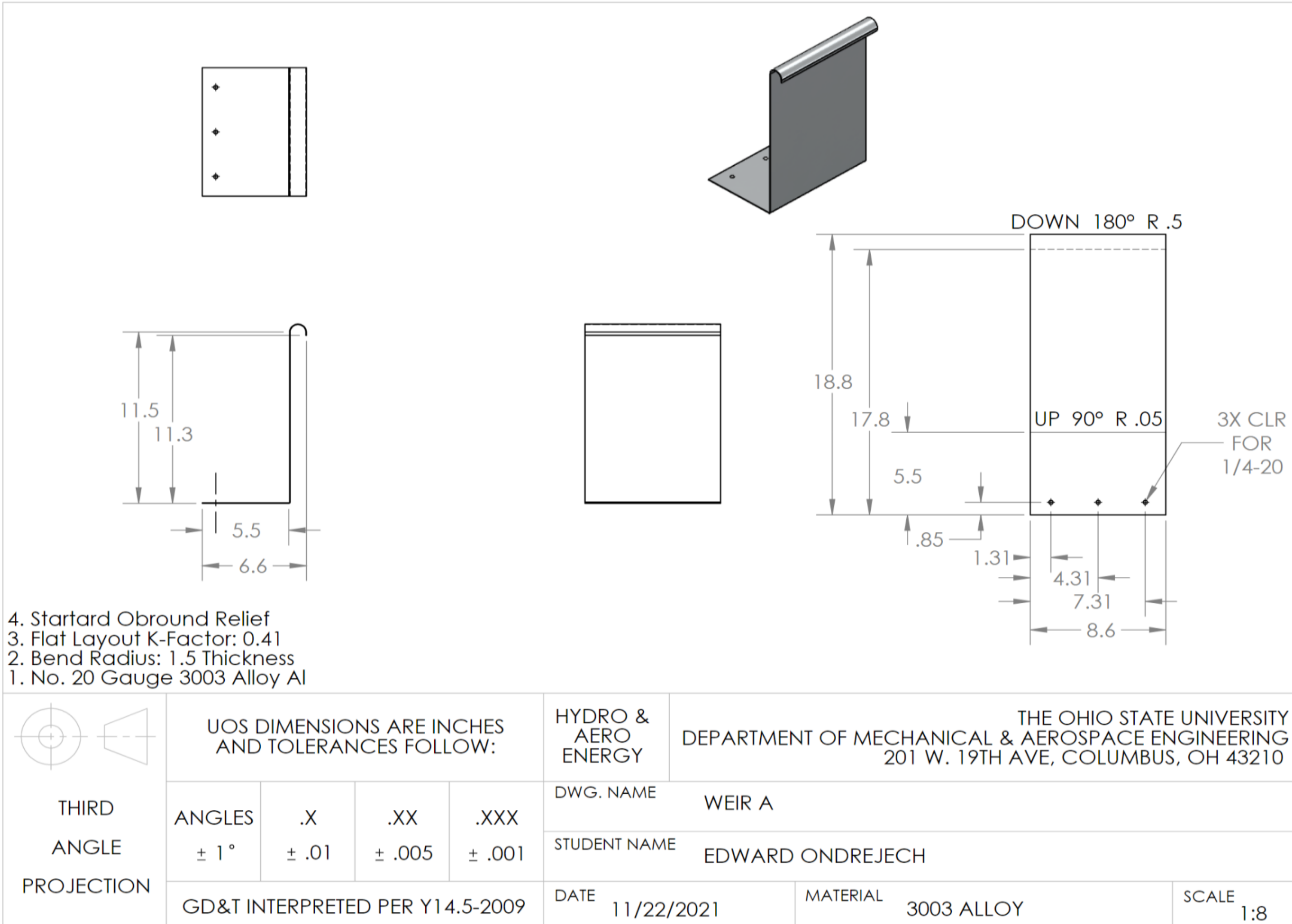


Figure A14: Weir Section A

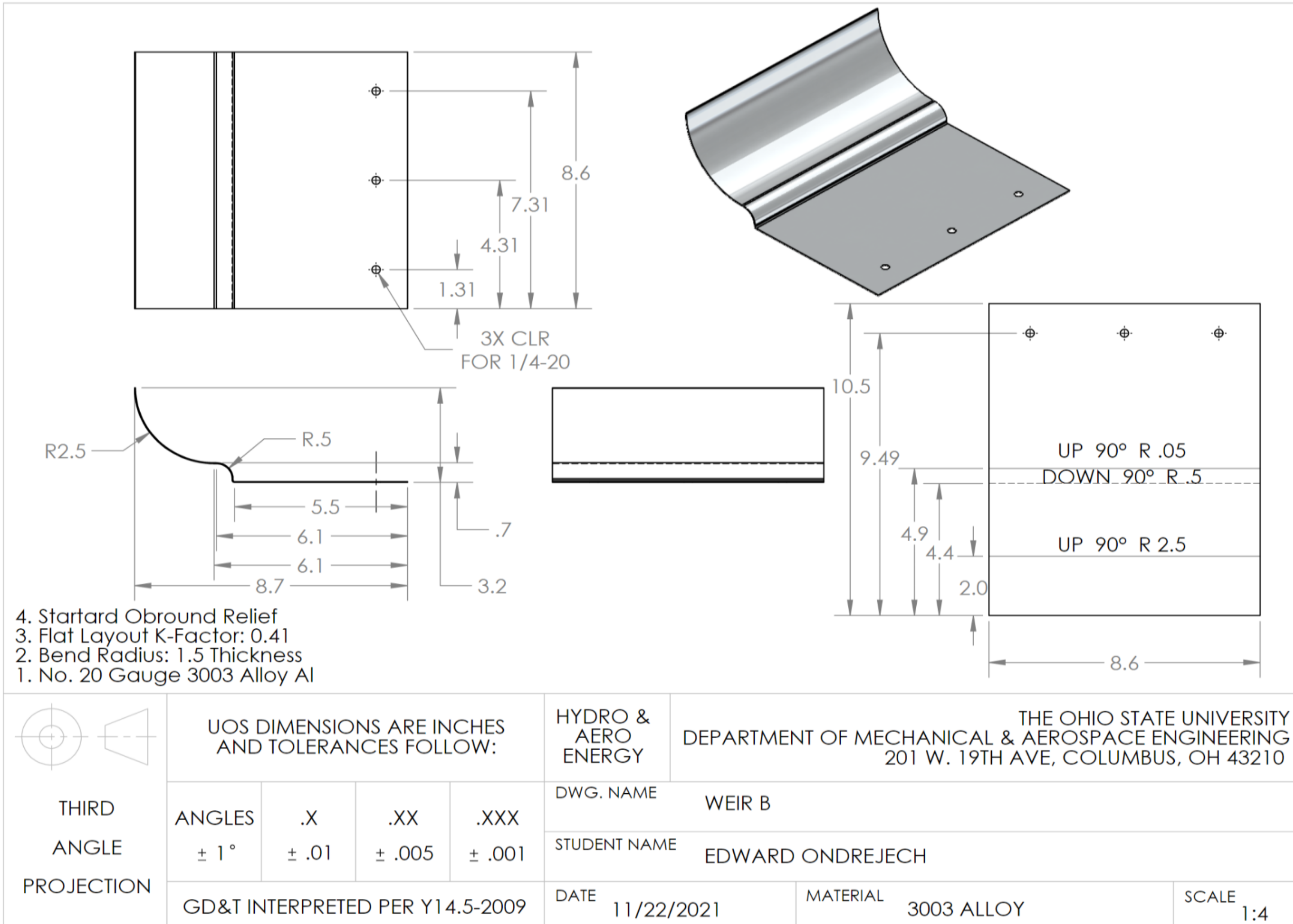


Figure A15: Weir Section B

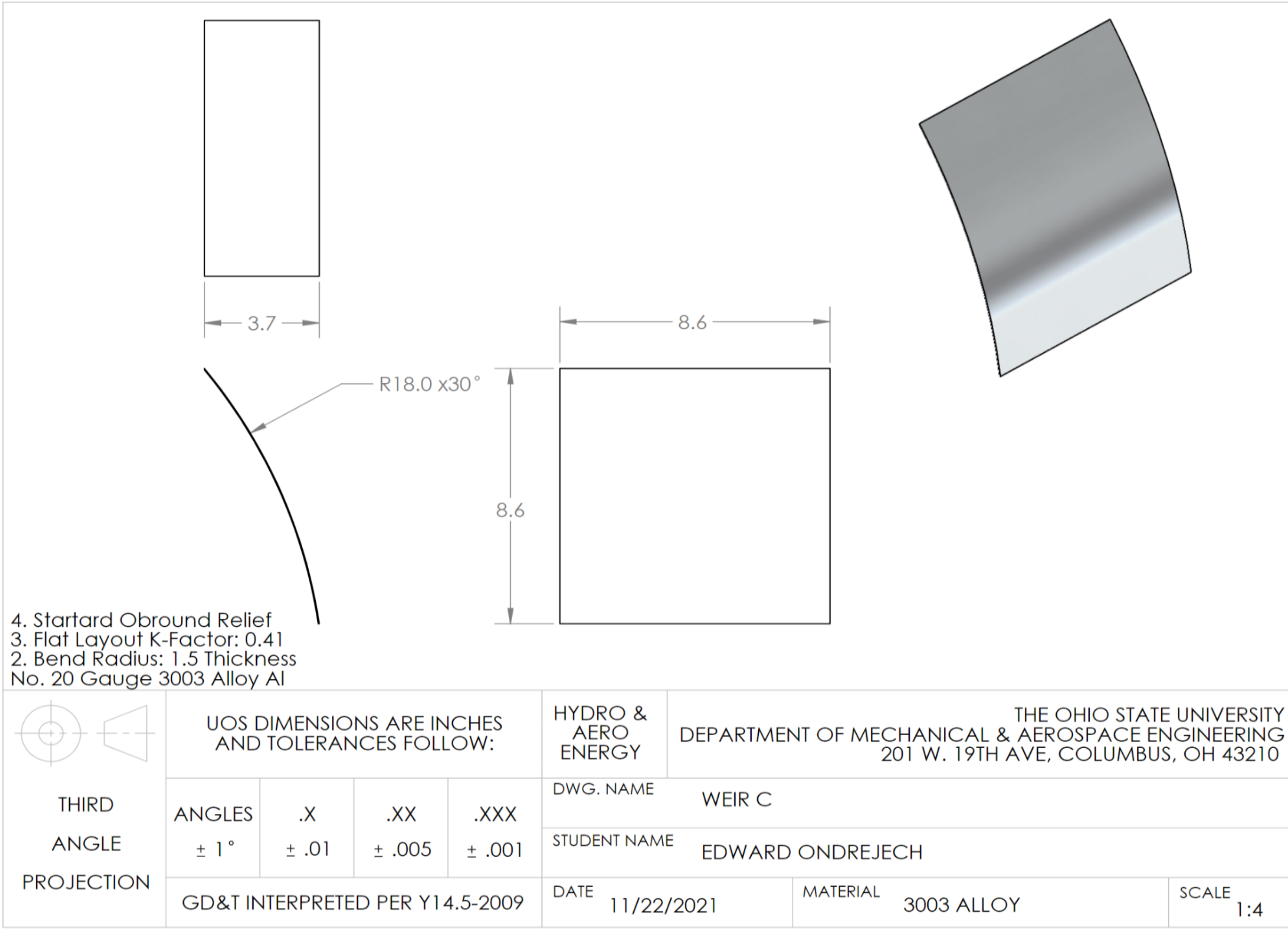


Figure A16: Weir Section C

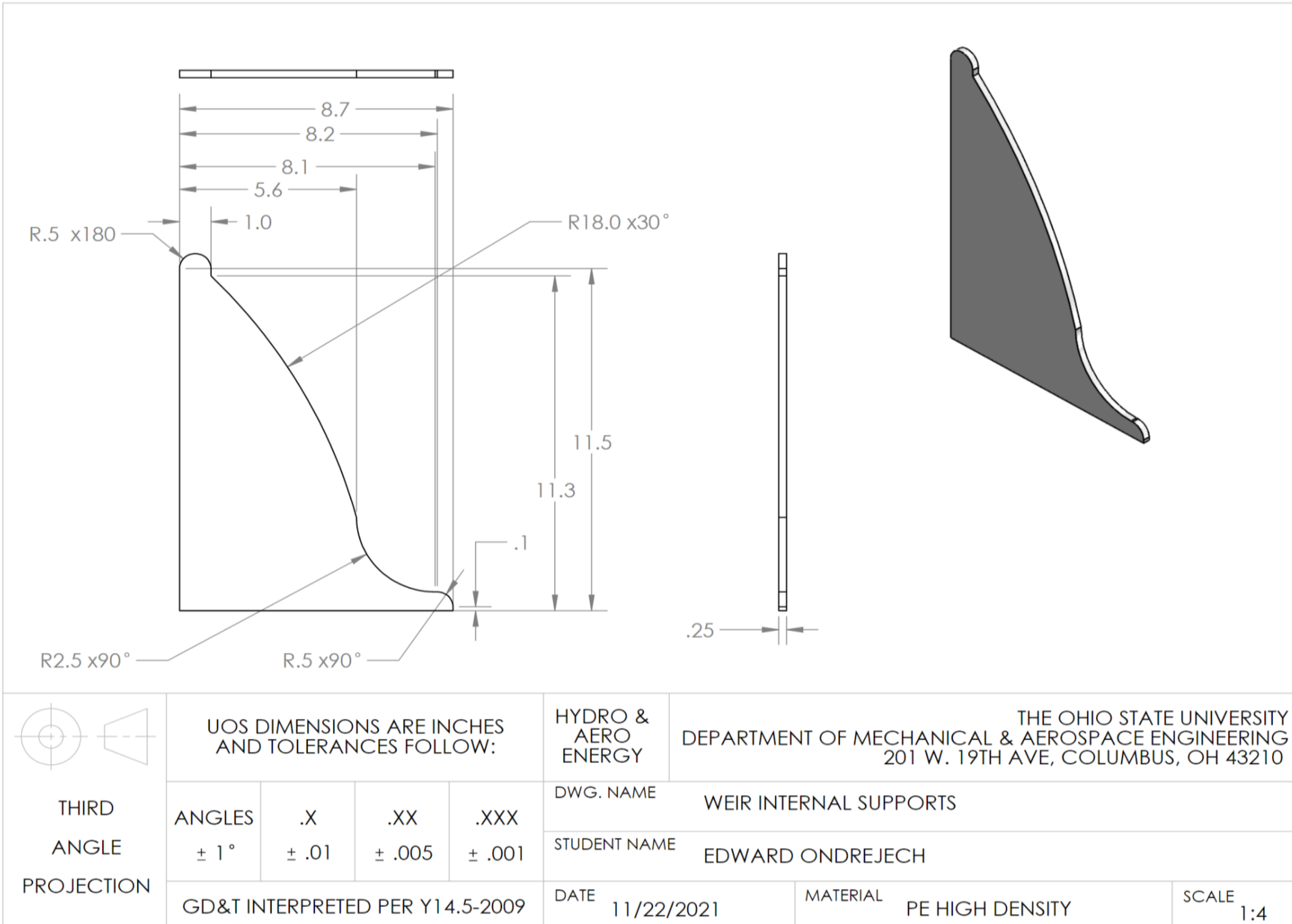


Figure A17: Weir Support

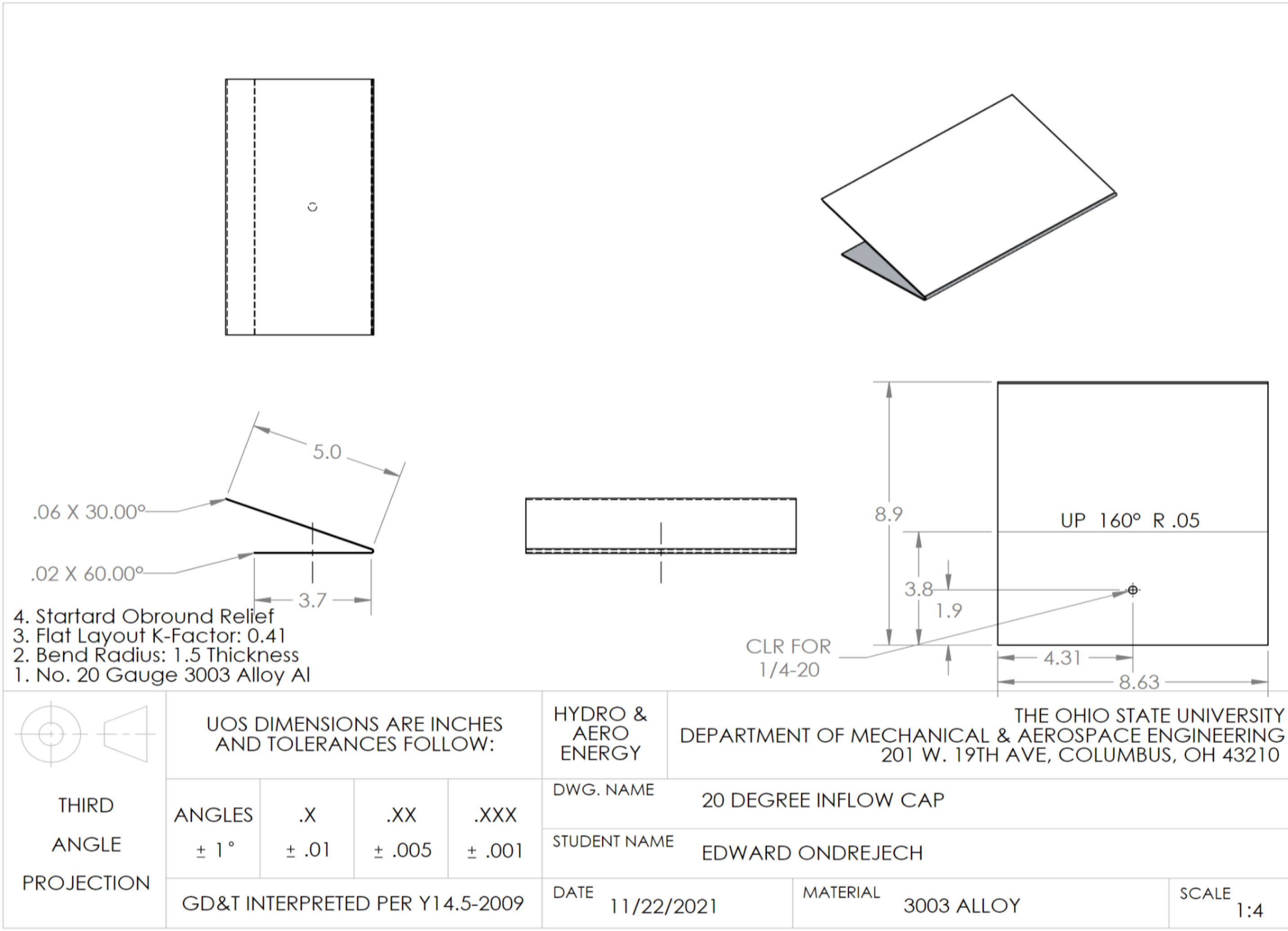


Figure A18: 20 Degree Cap

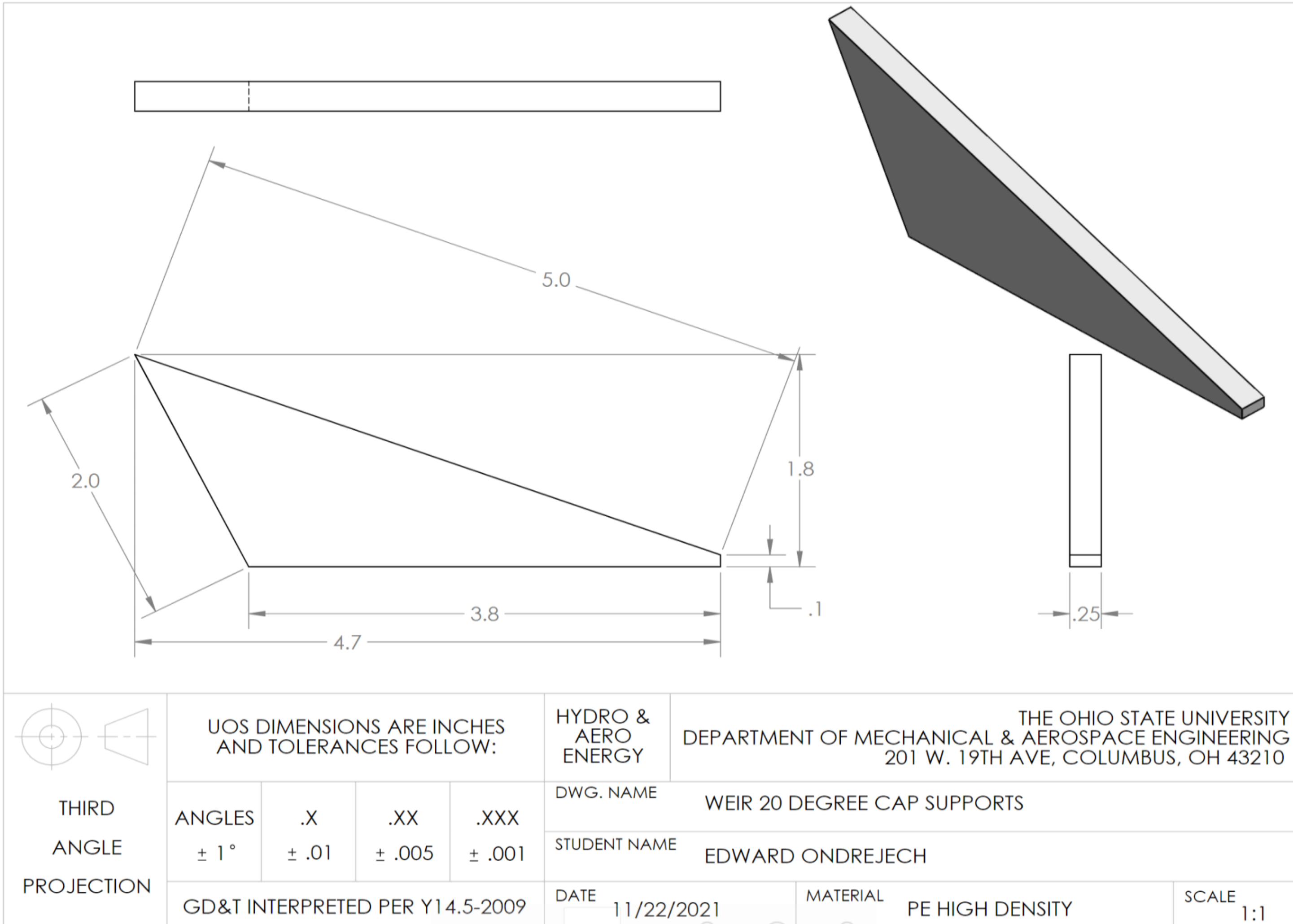


Figure A19: 20 Degree Cap Supports

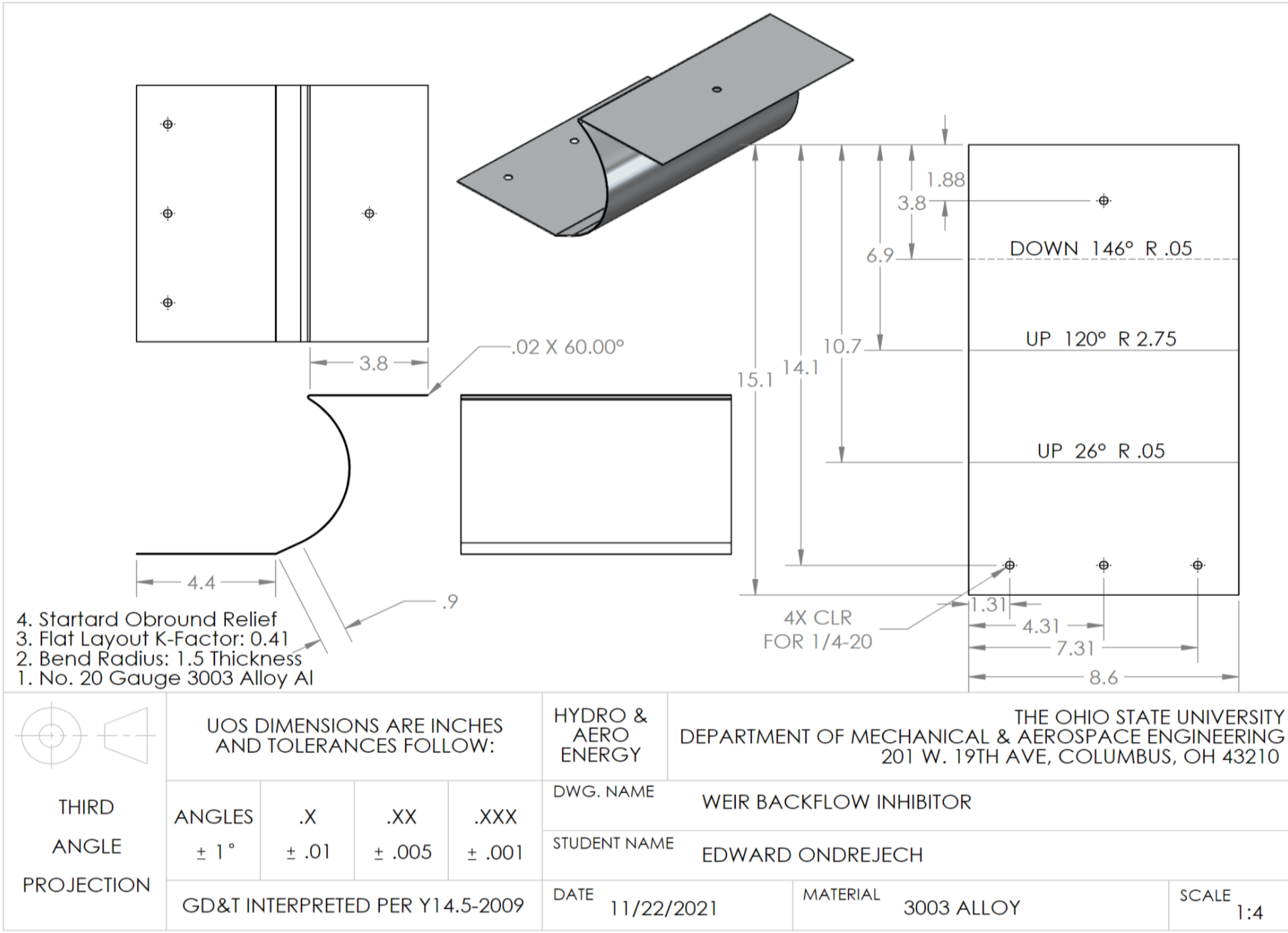
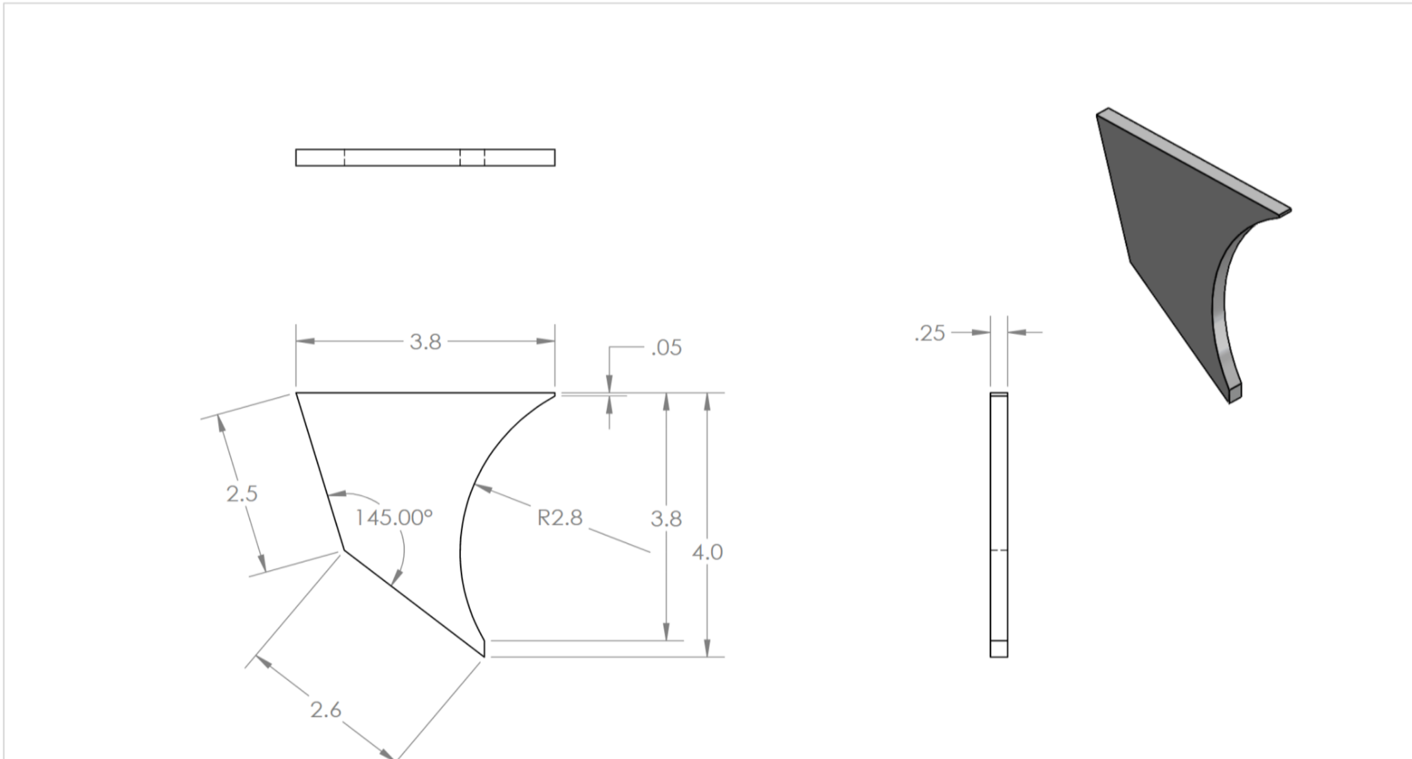


Figure A20: Backsplash Inhibitor



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	ANGLES ± 1°	.X ± .01	.XX ± .005	.XXX ± .001	DWG. NAME	WEIR BACKFLOW INHIBITOR SUPPORTS	
					STUDENT NAME	EDWARD ONDREJECH	
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Figure A21: Backsplash Inhibitor Supports

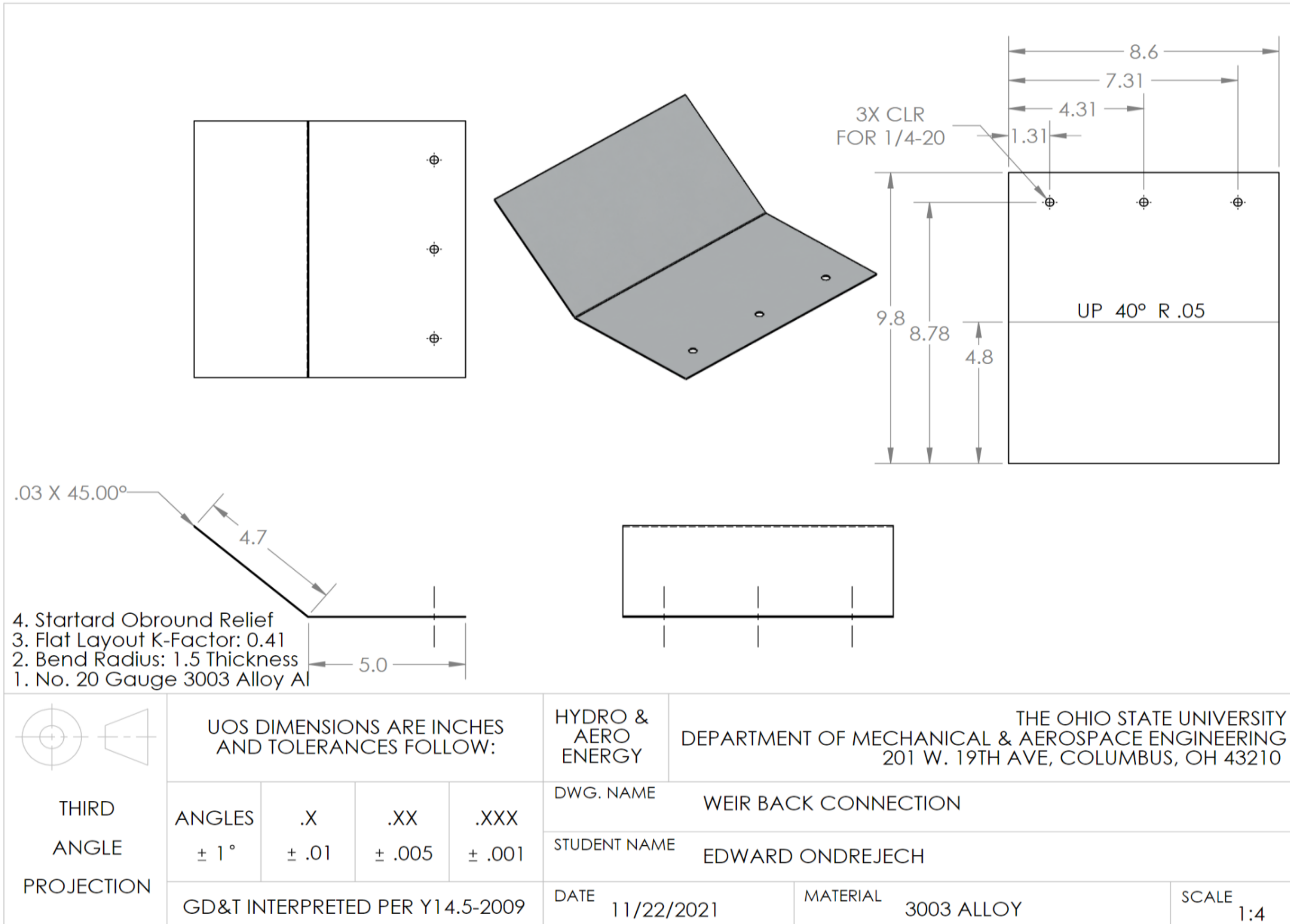

Figure A22: Weir Backing

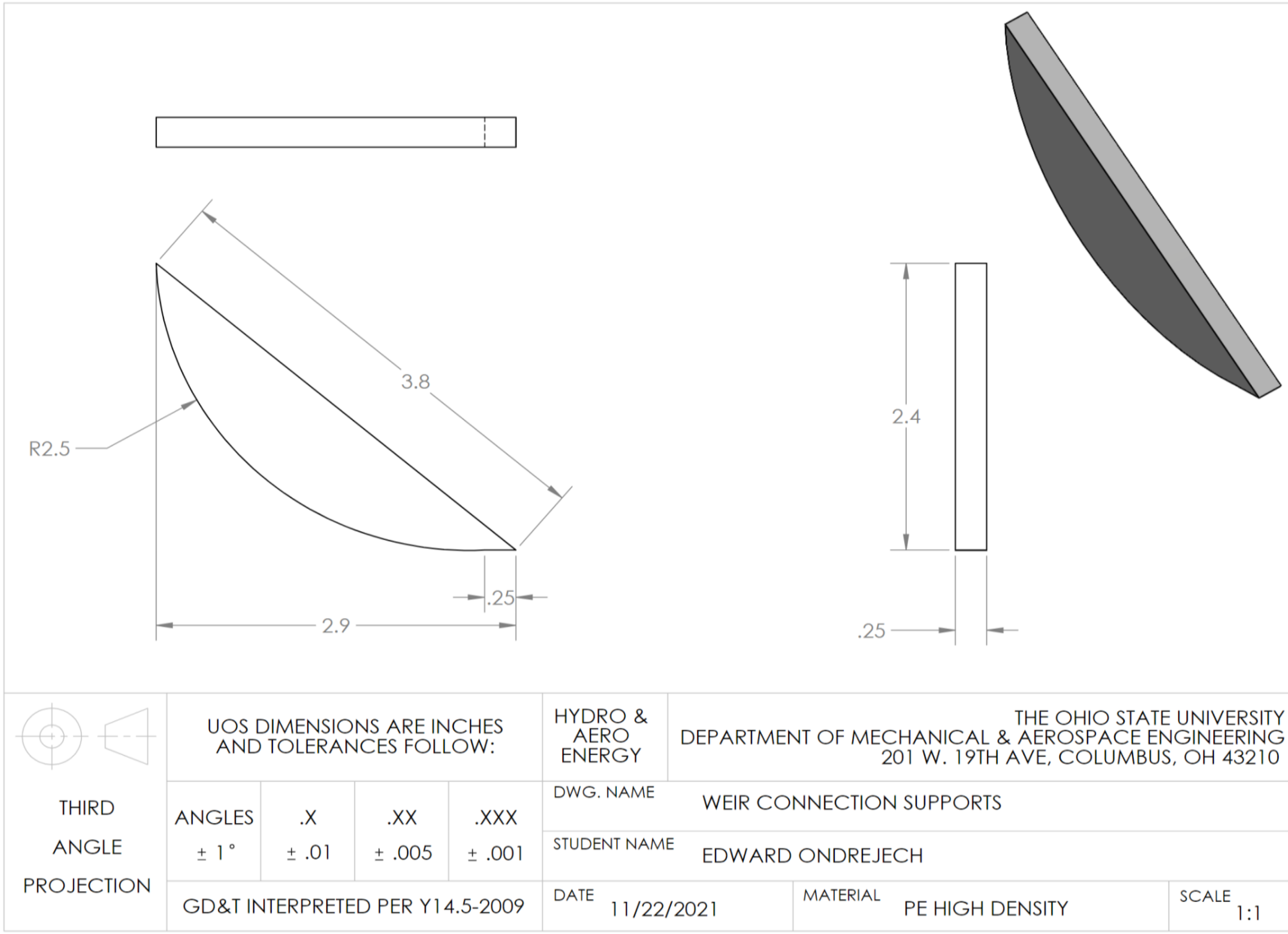

Figure A23: Weir Backing Supports

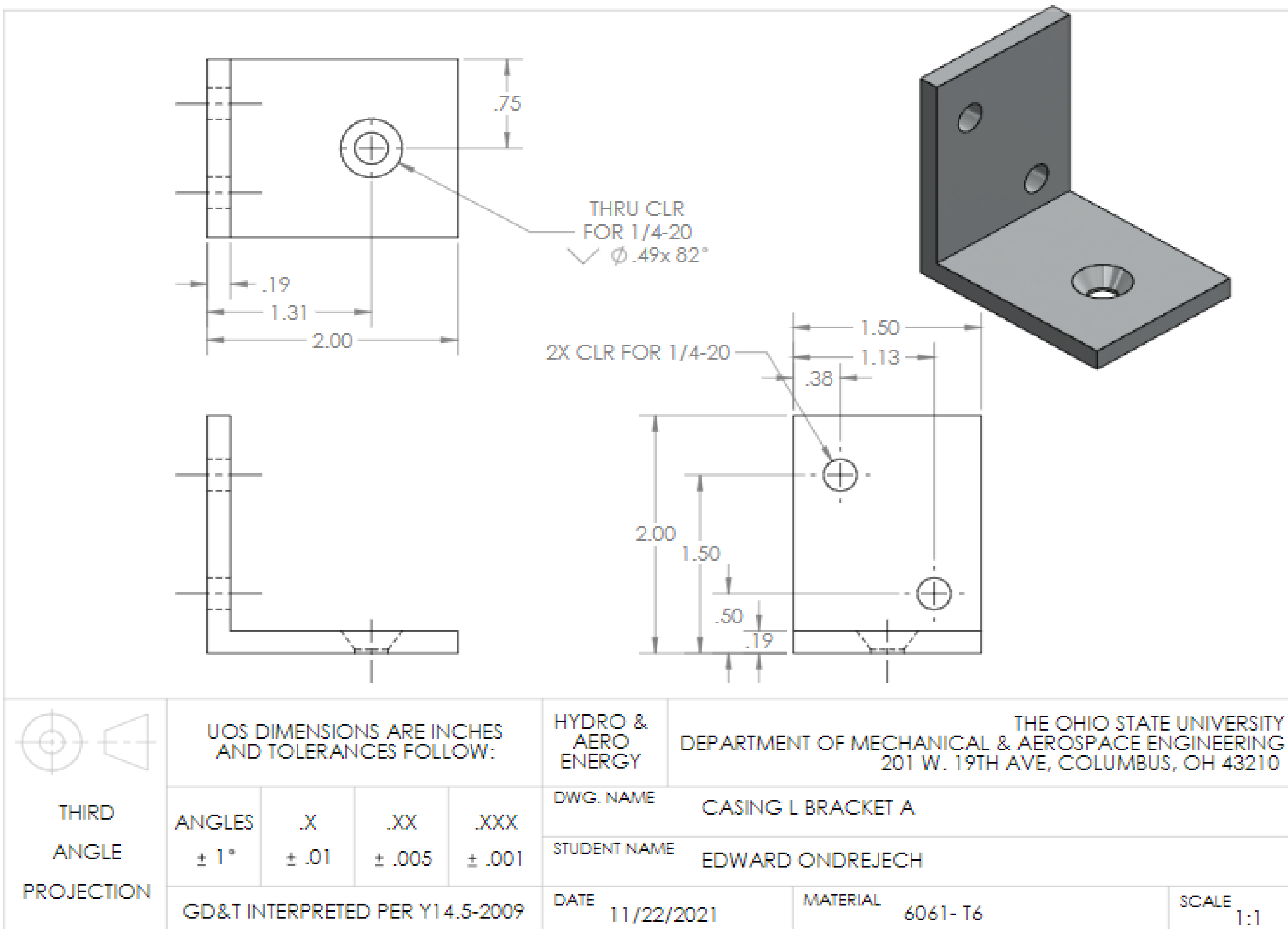

Figure A24: Casing L Bracket A

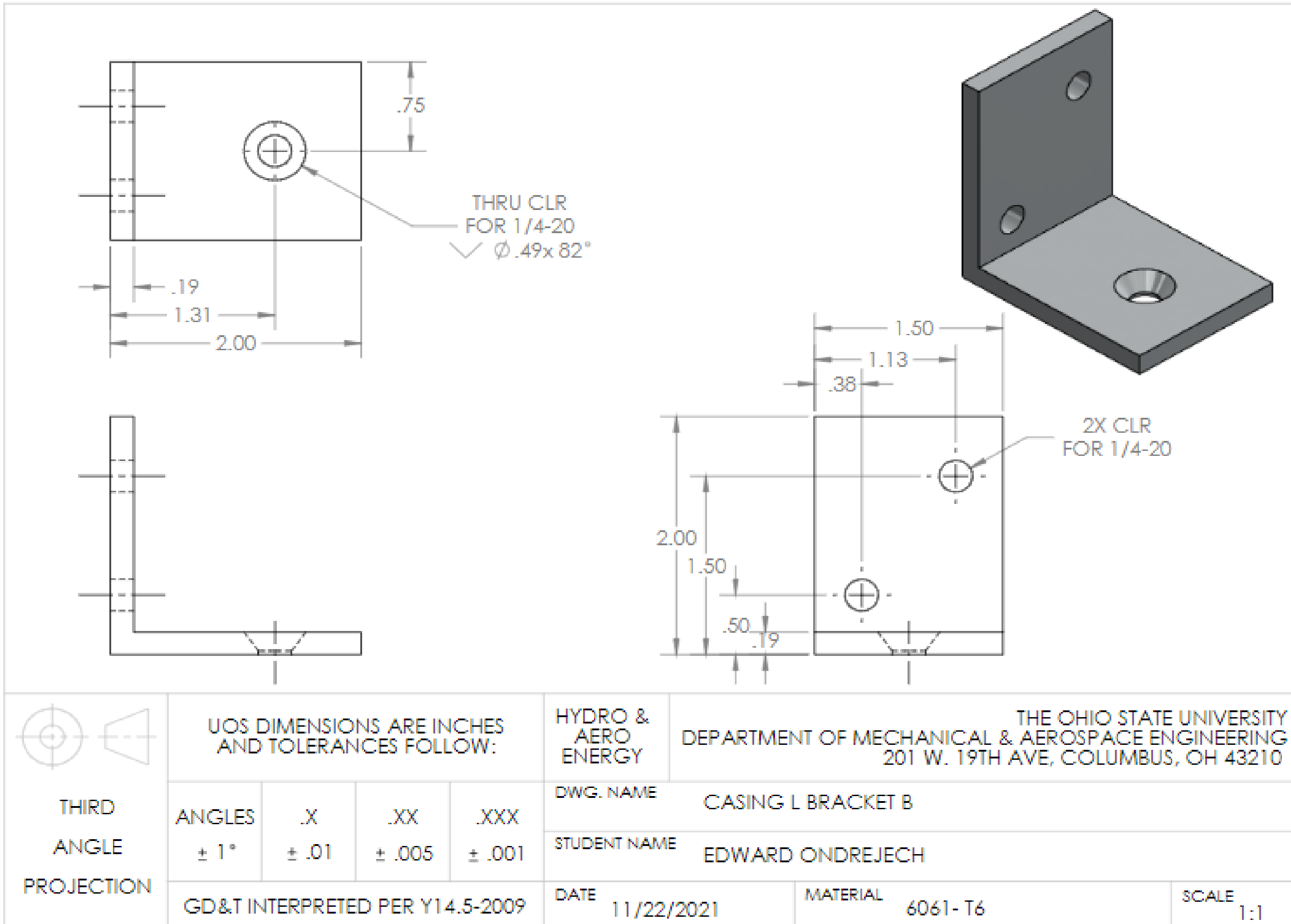

Figure A 25: Casing L Bracket B

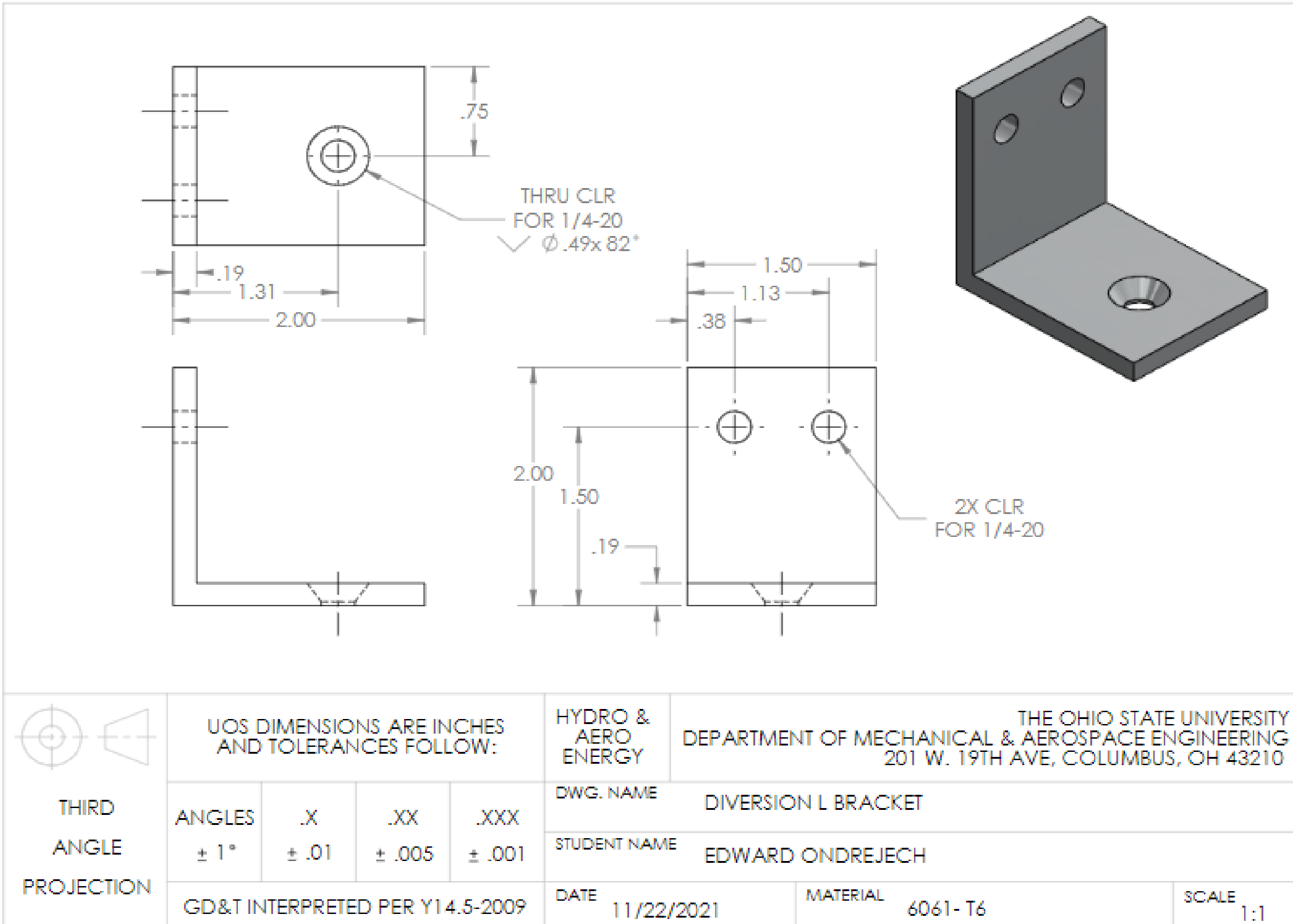

Figure A26: Diversion L Bracket

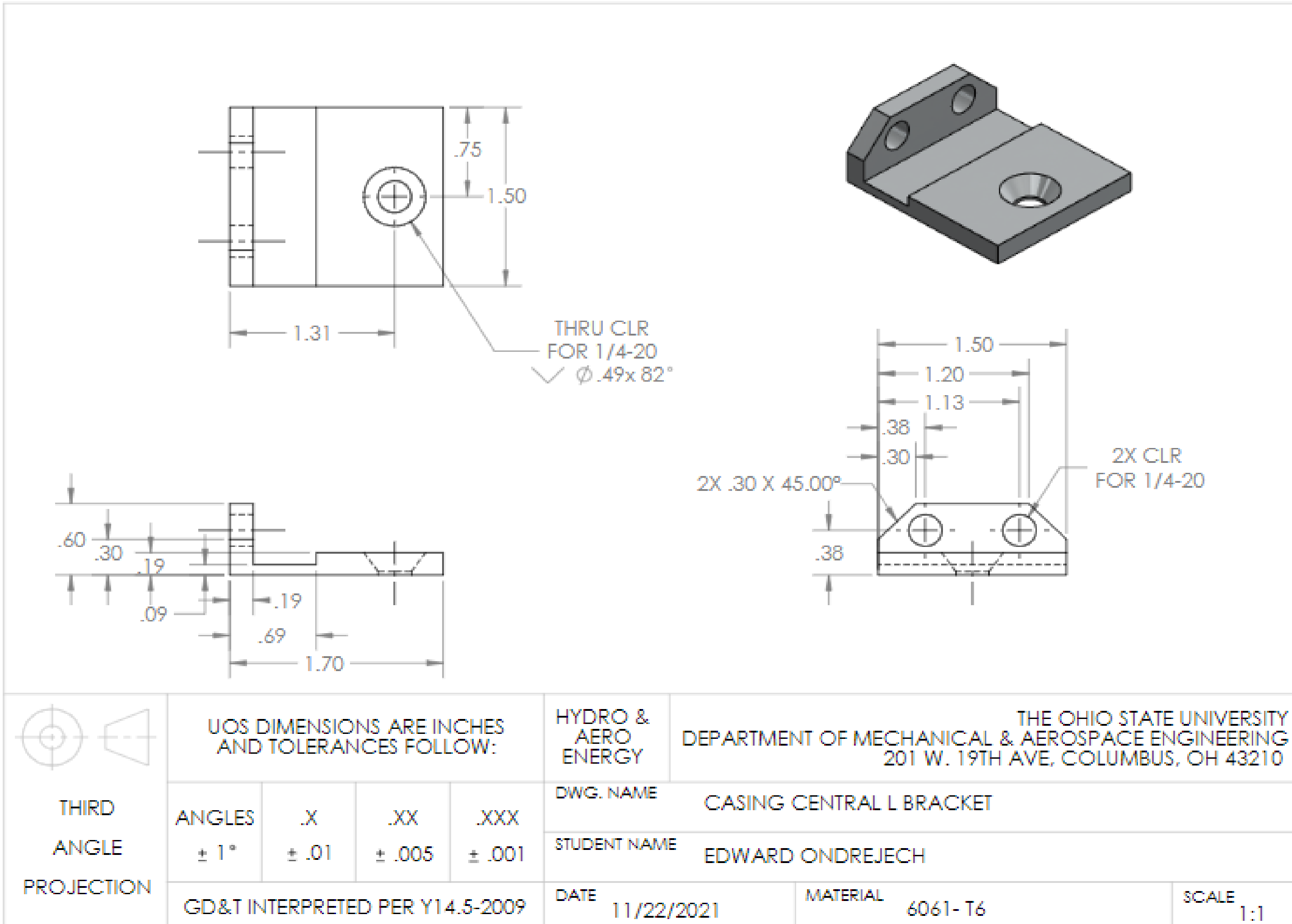

Figure A27: Casing Central L Bracket

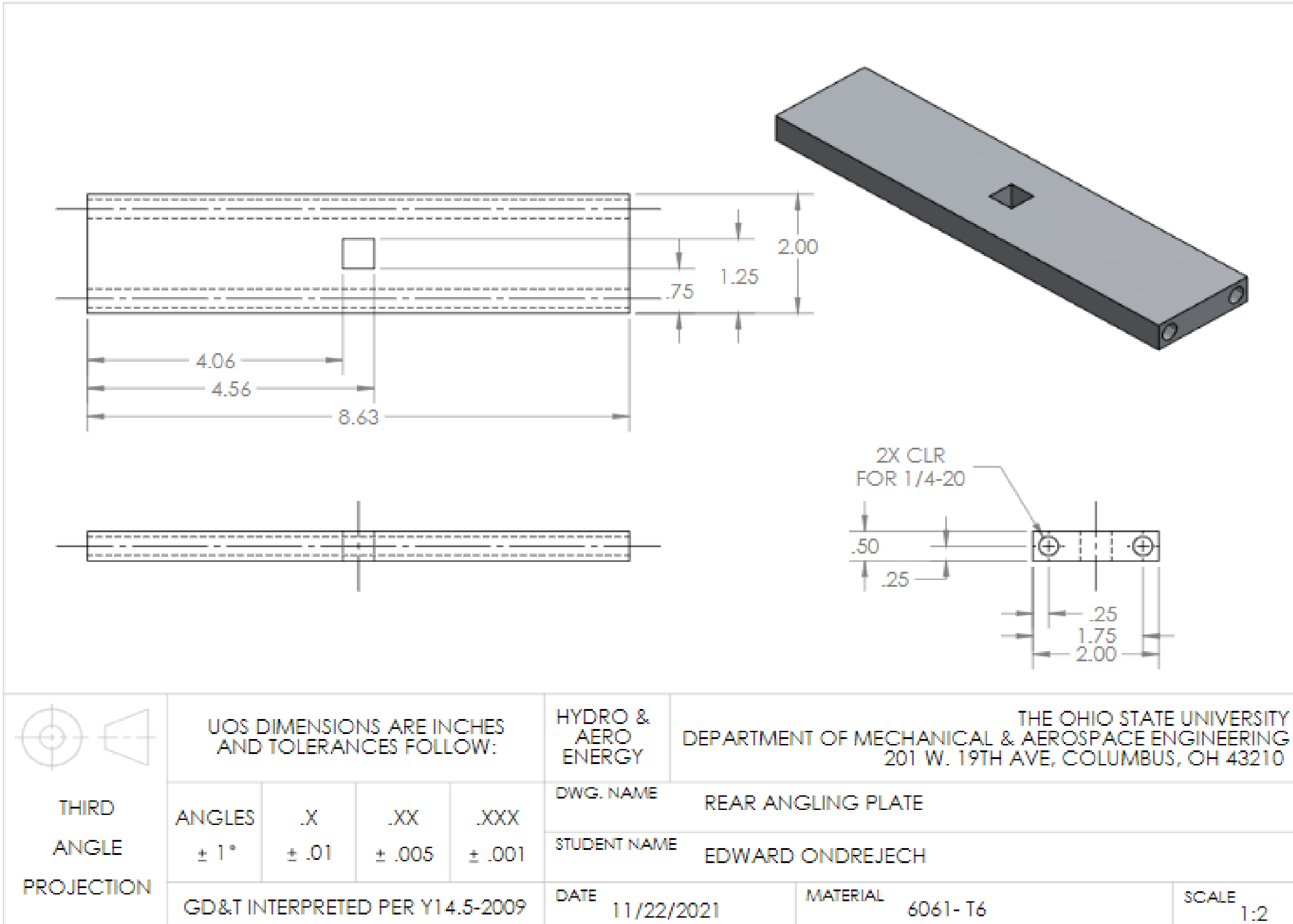

Figure A28: Rear Angling Plate

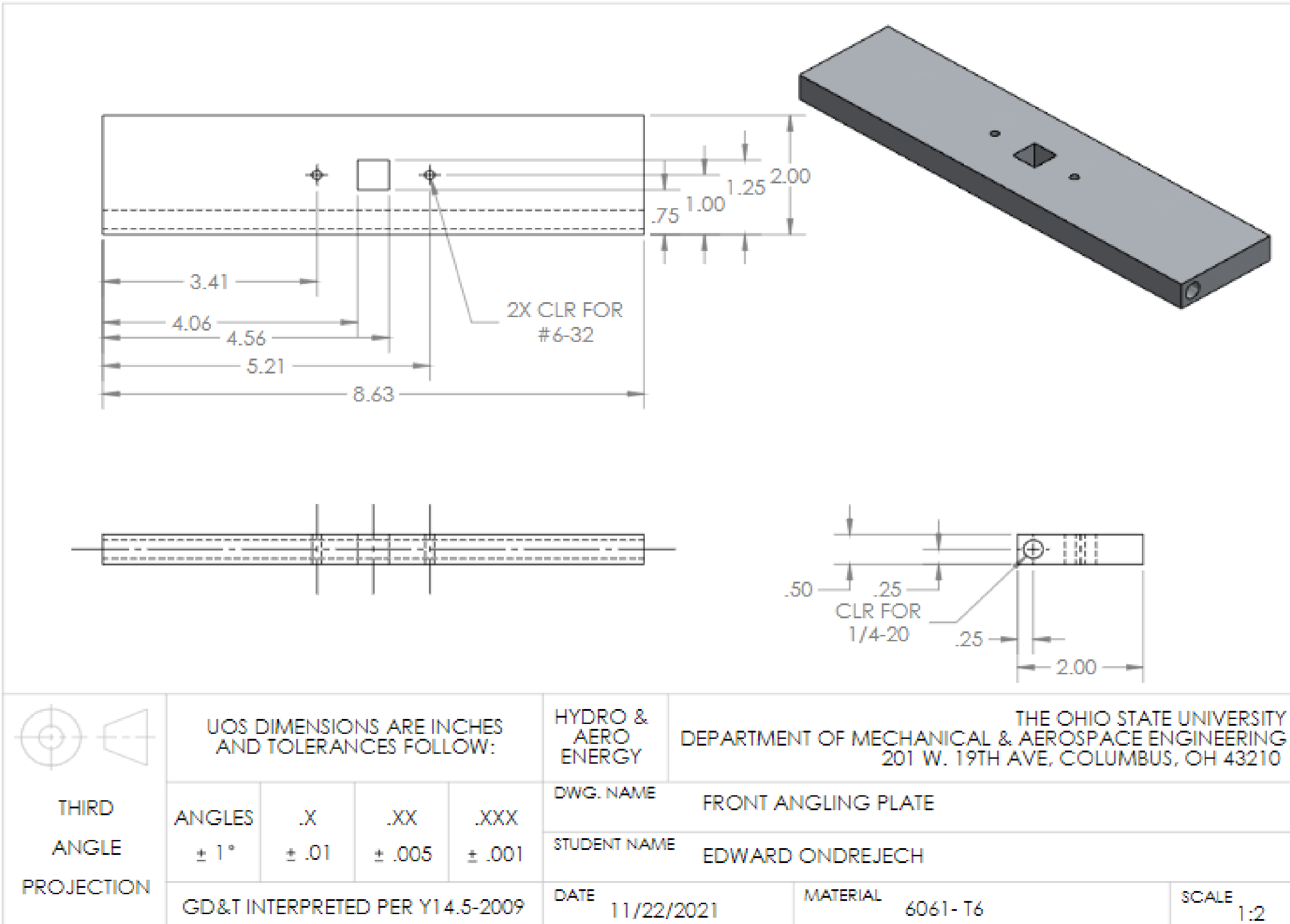

Figure A29: Front Angling Plate

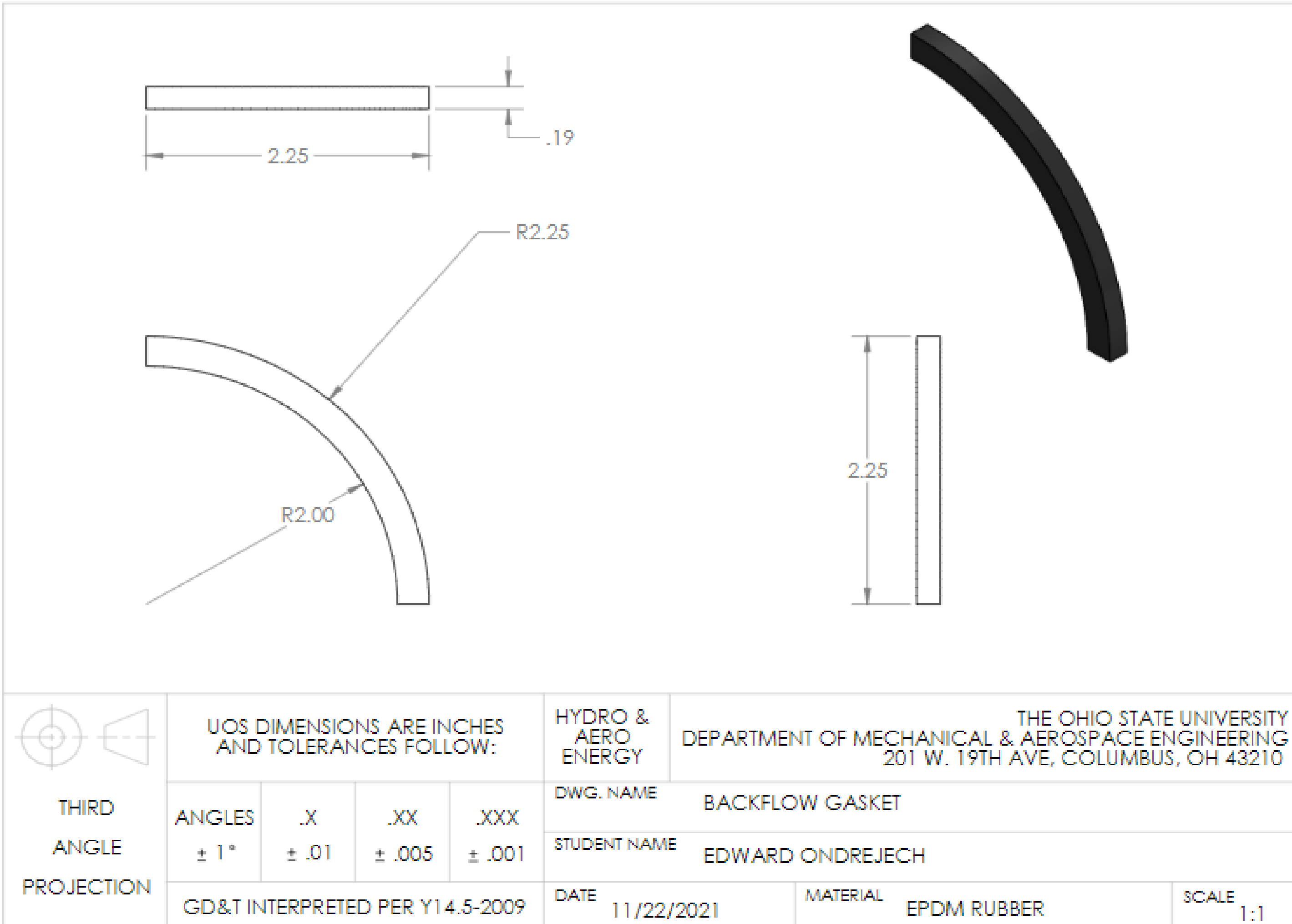

Figure A30: Backflow Gasket

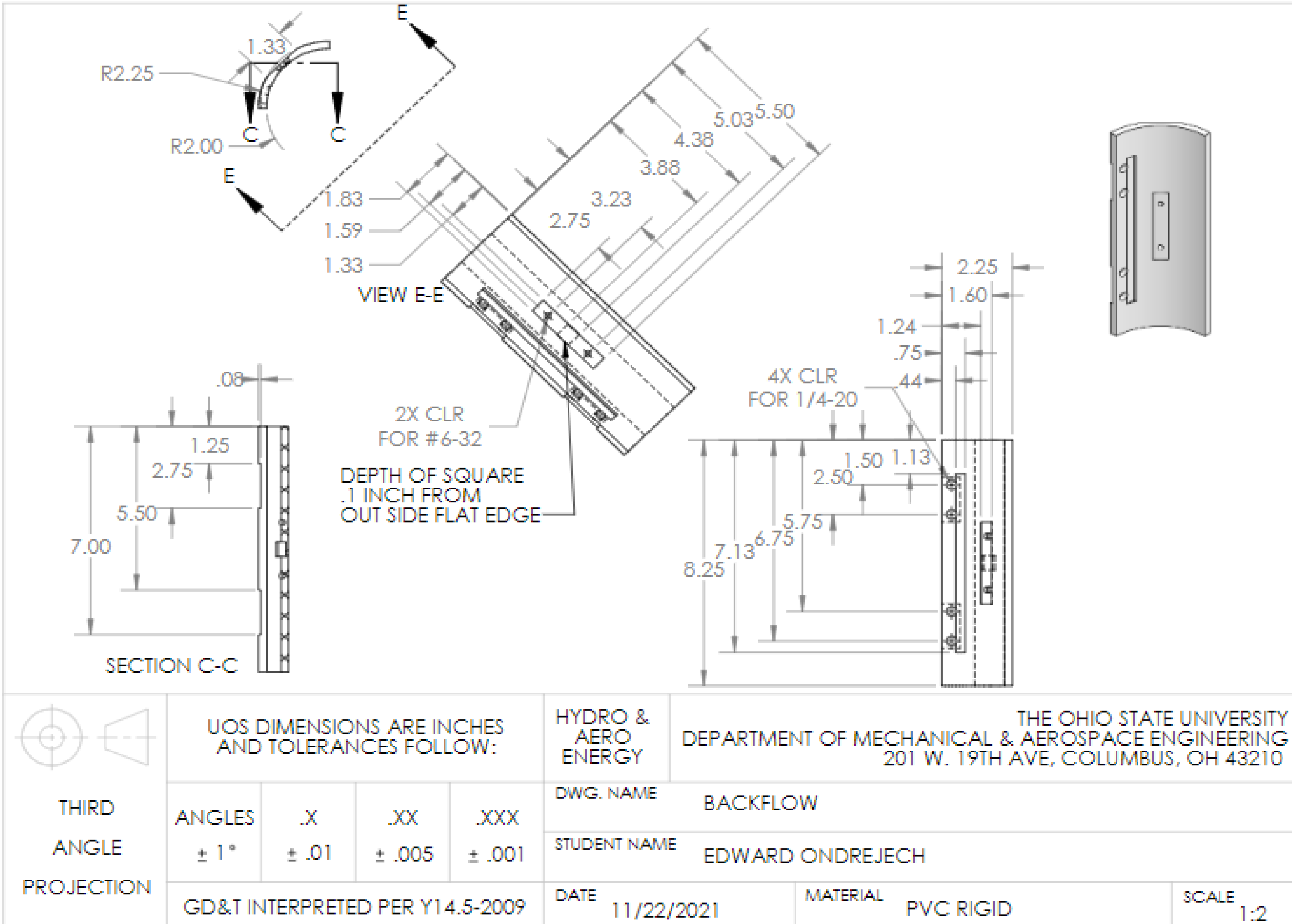

Figure A31: Backflow

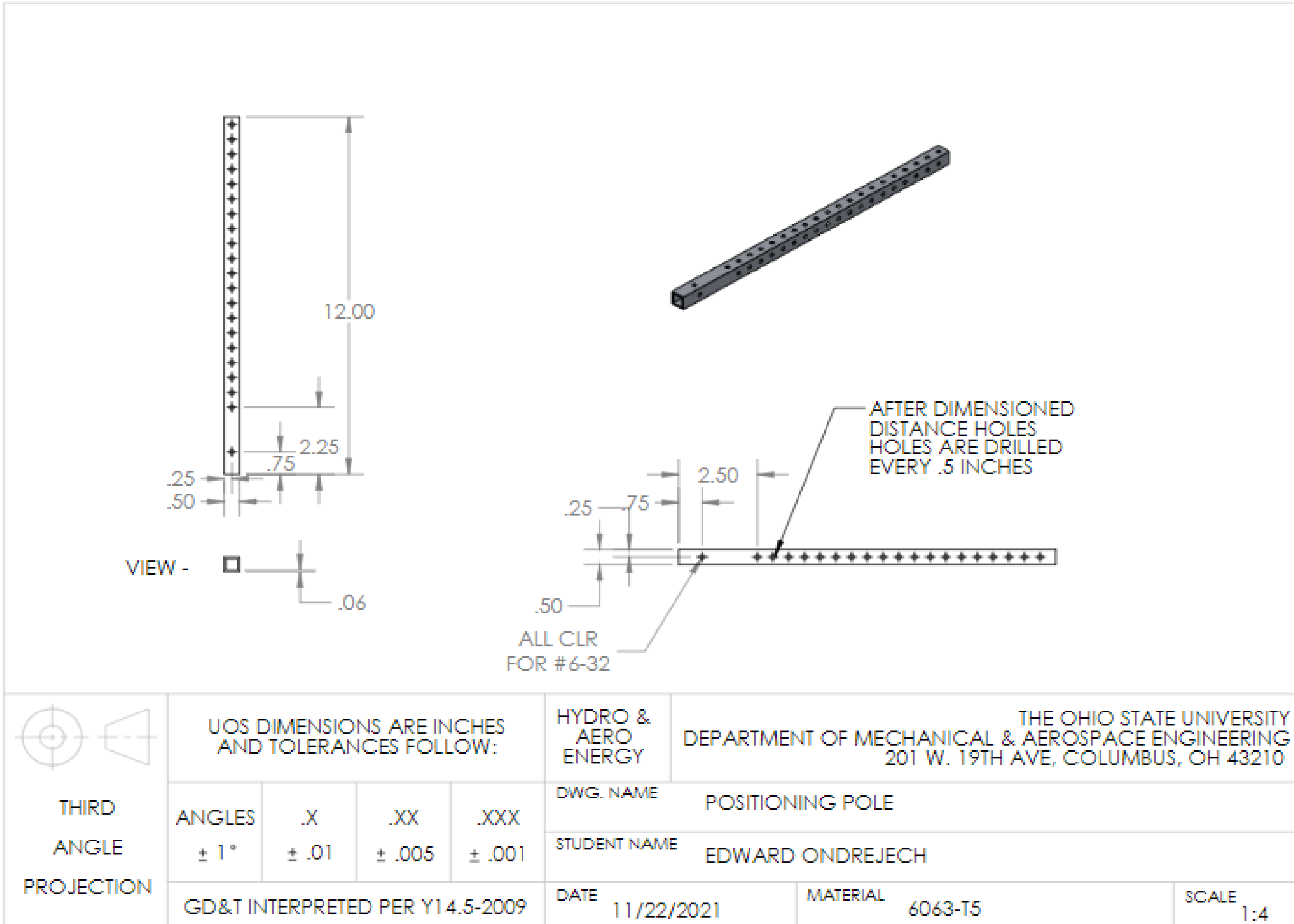

Figure A32: Positioning Pole

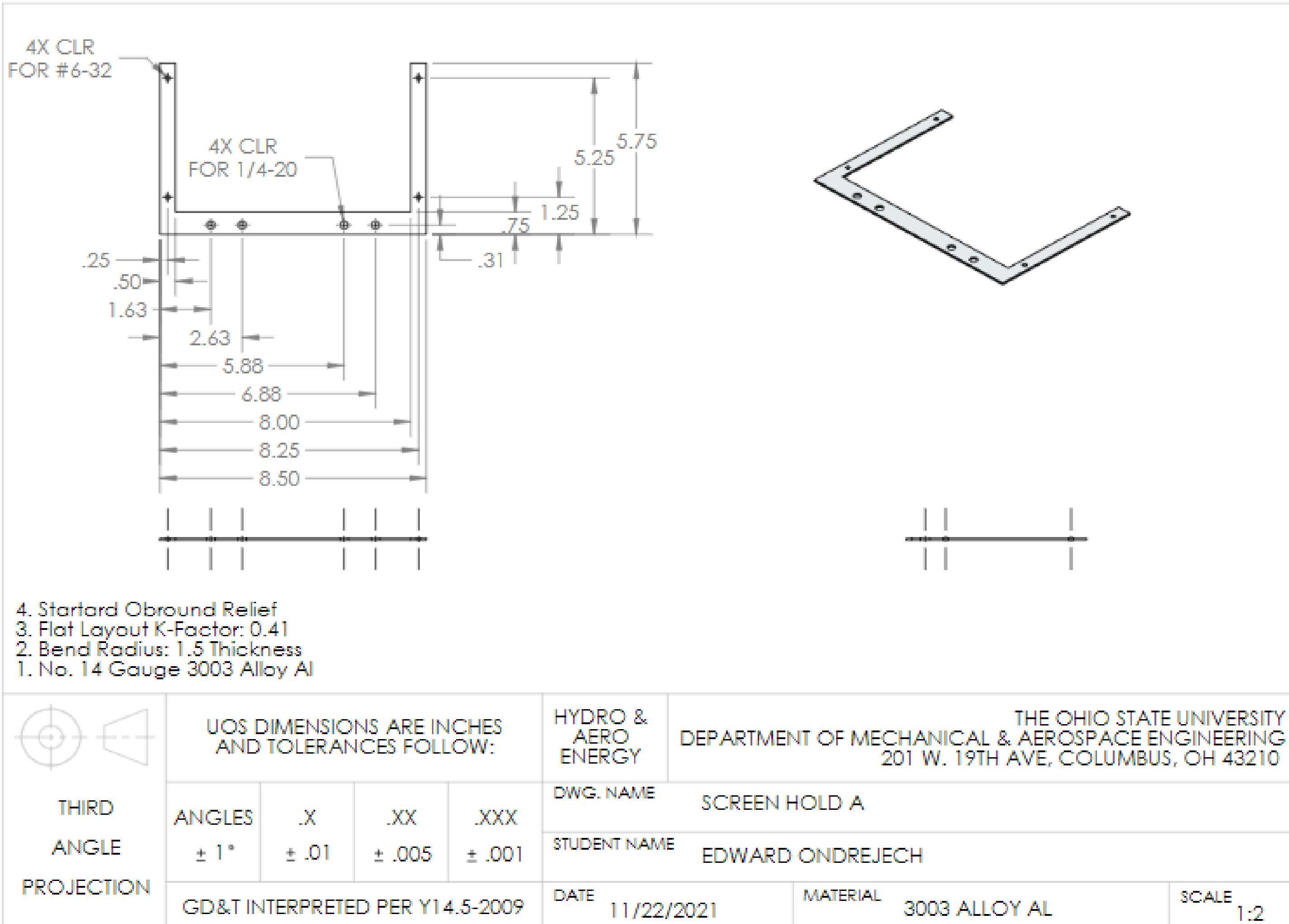

Figure A33: Screen Hold A

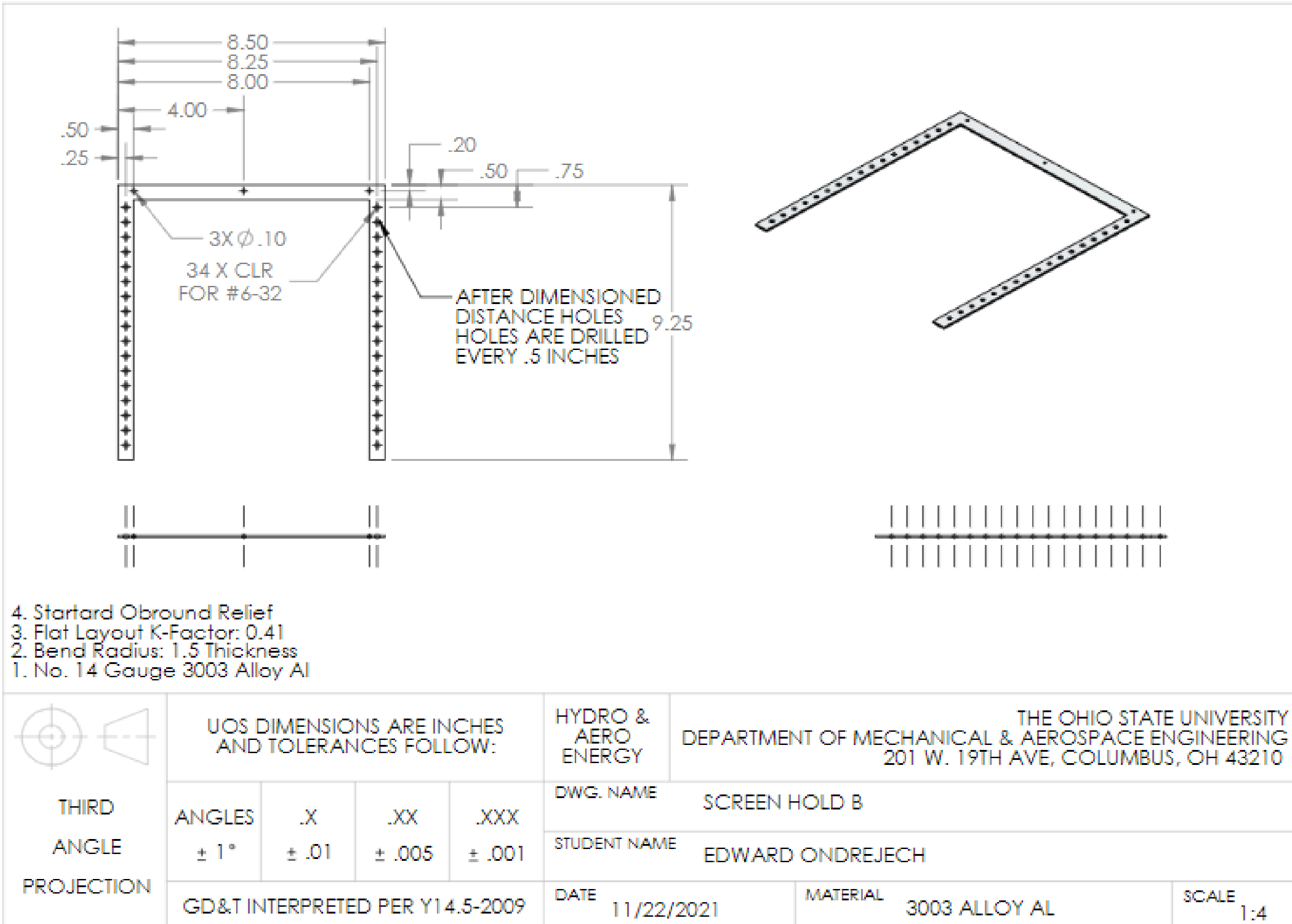

Figure A34: Screen Hold B

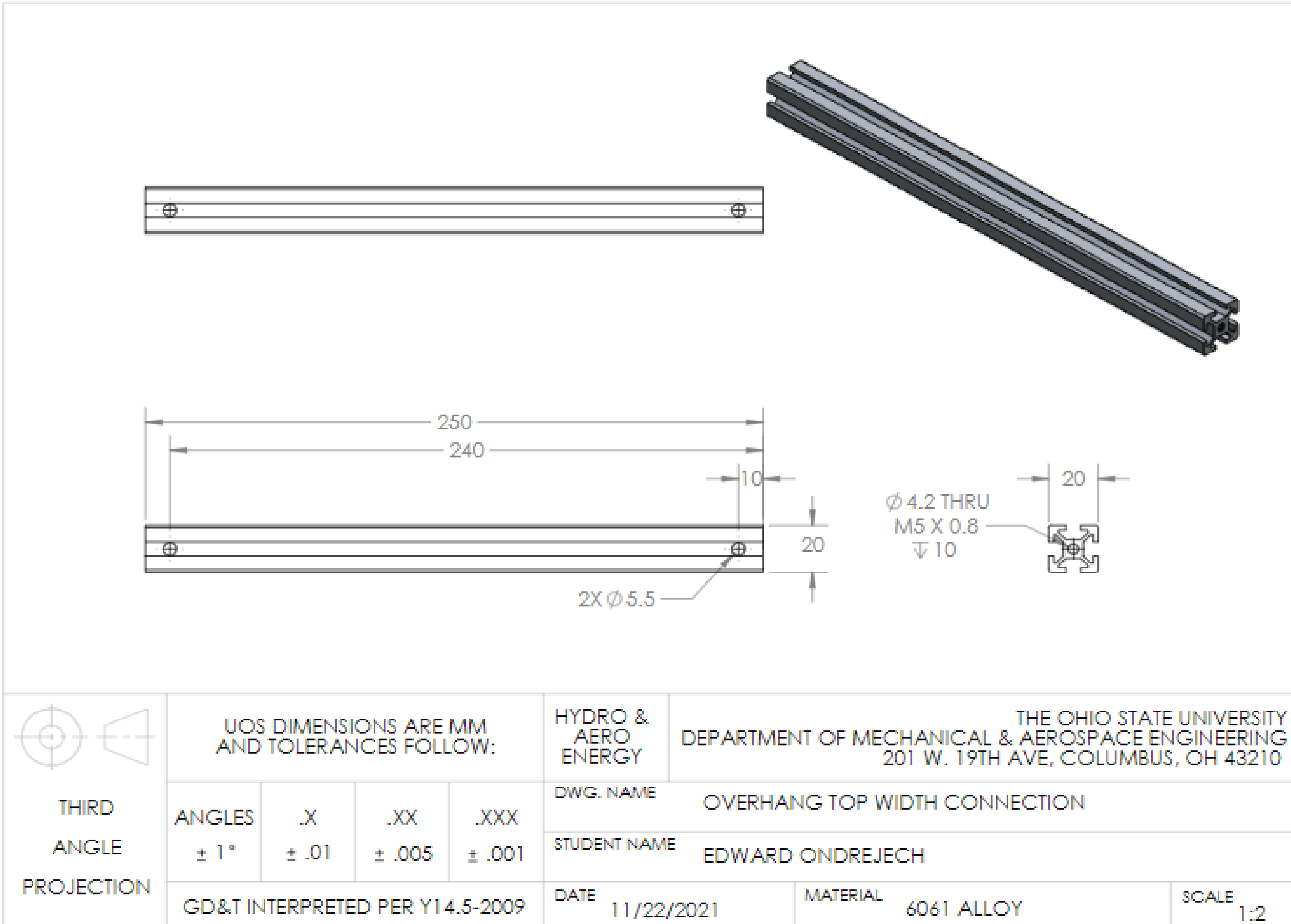

Figure A35: Overhang Top Width Connection

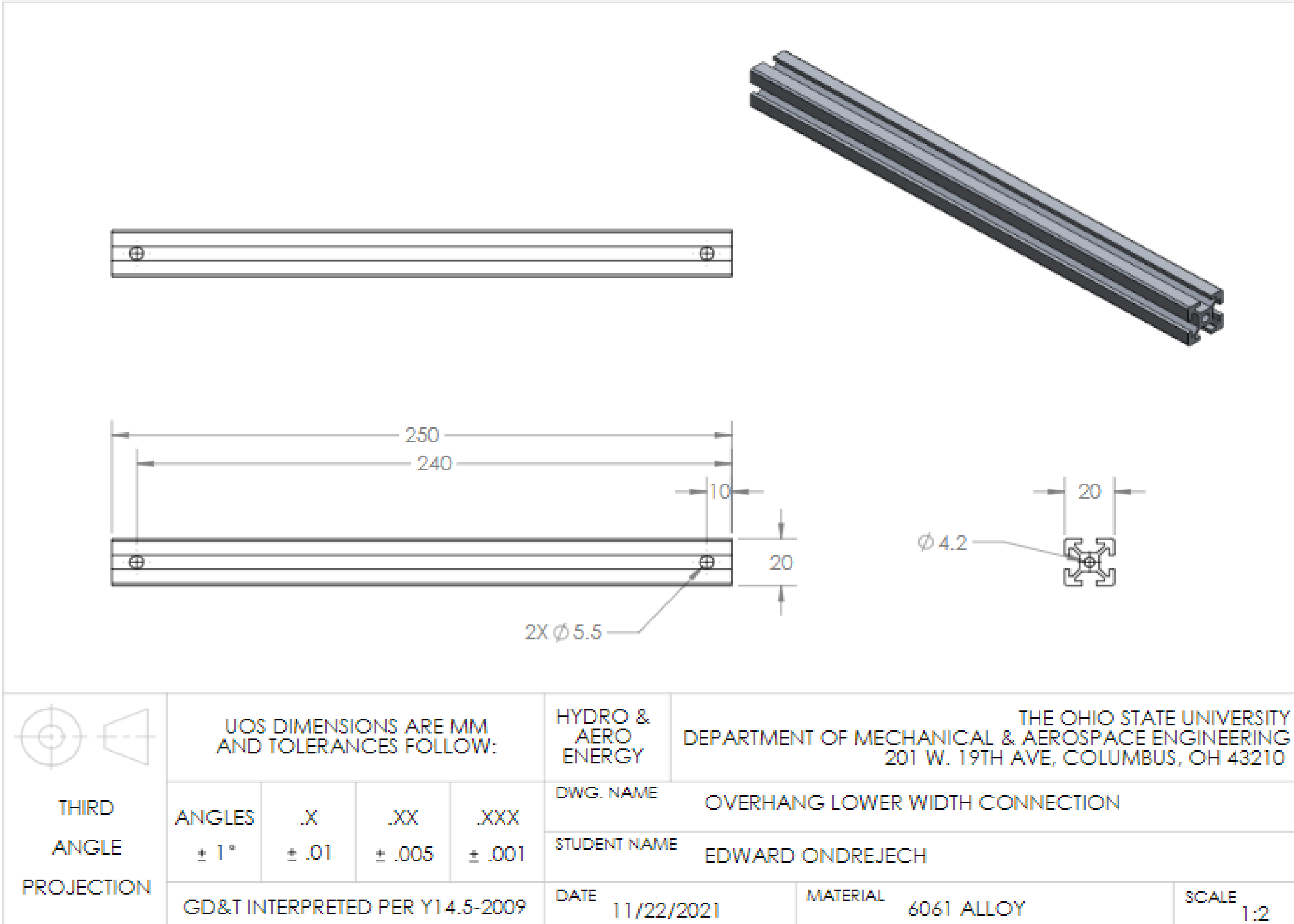

Figure A36: Overhang Lower Width Connection

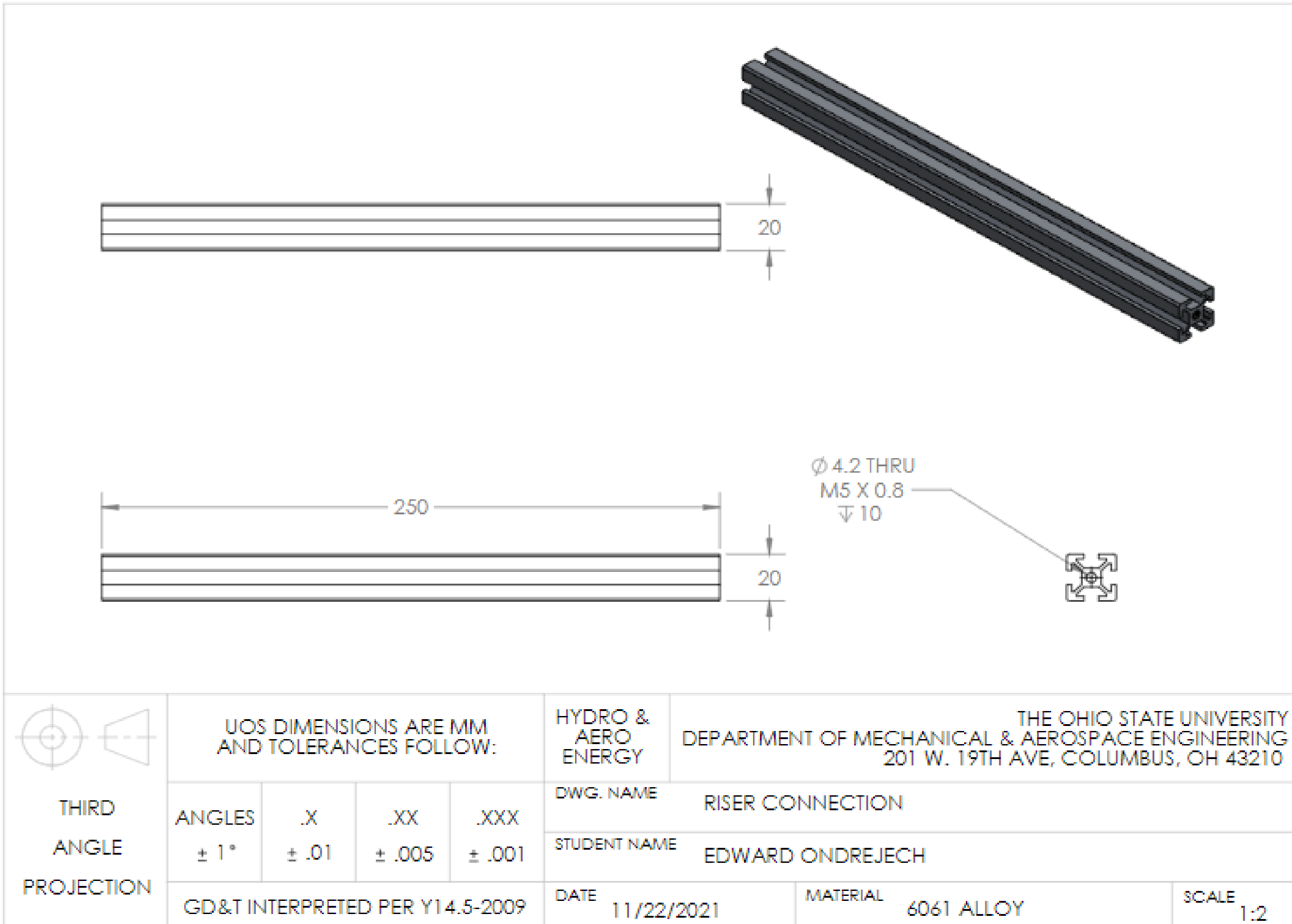

Figure A37: Riser Connection

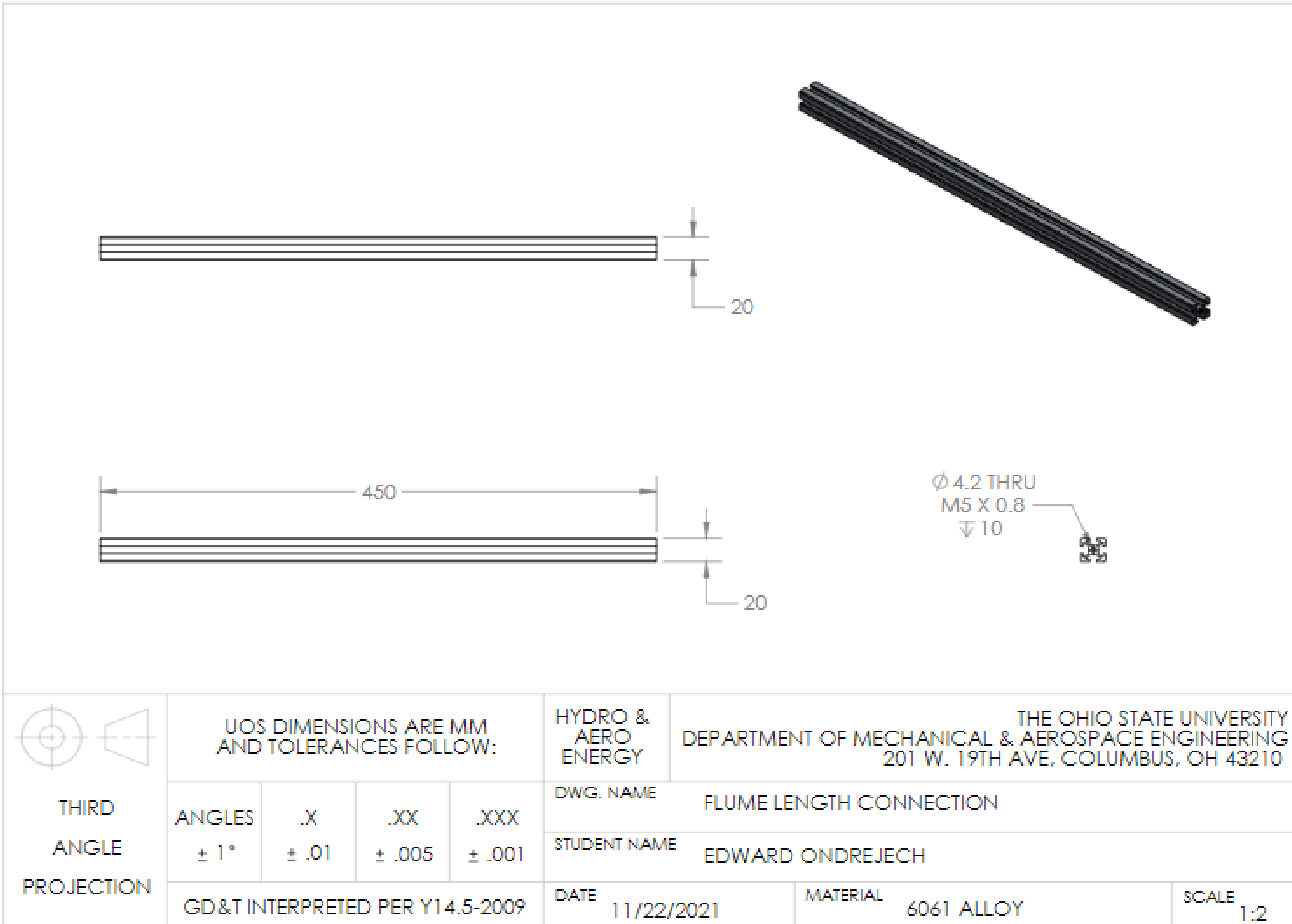

Figure A38: Flume Length Connection

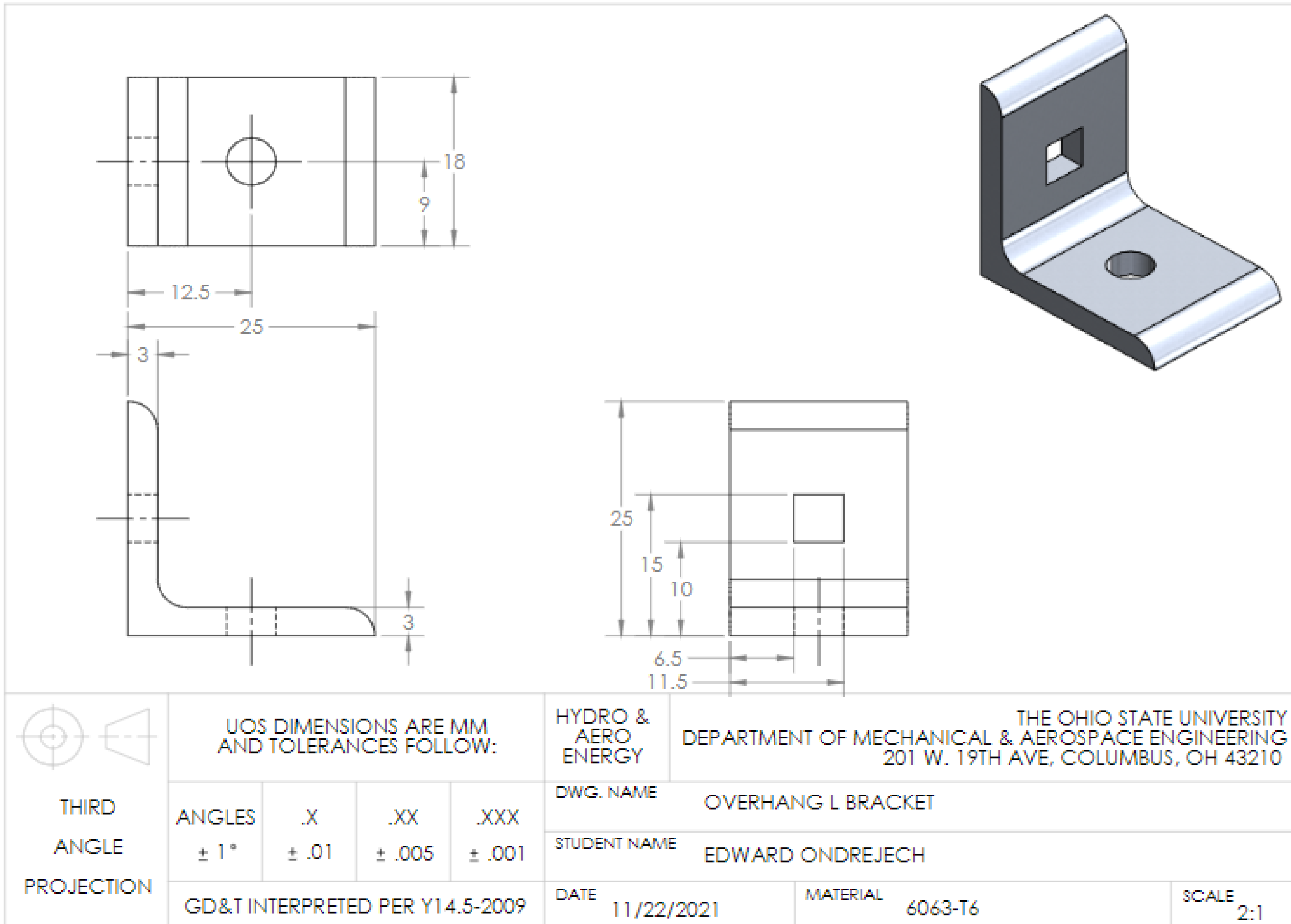

Figure A39: Overhang L Bracket

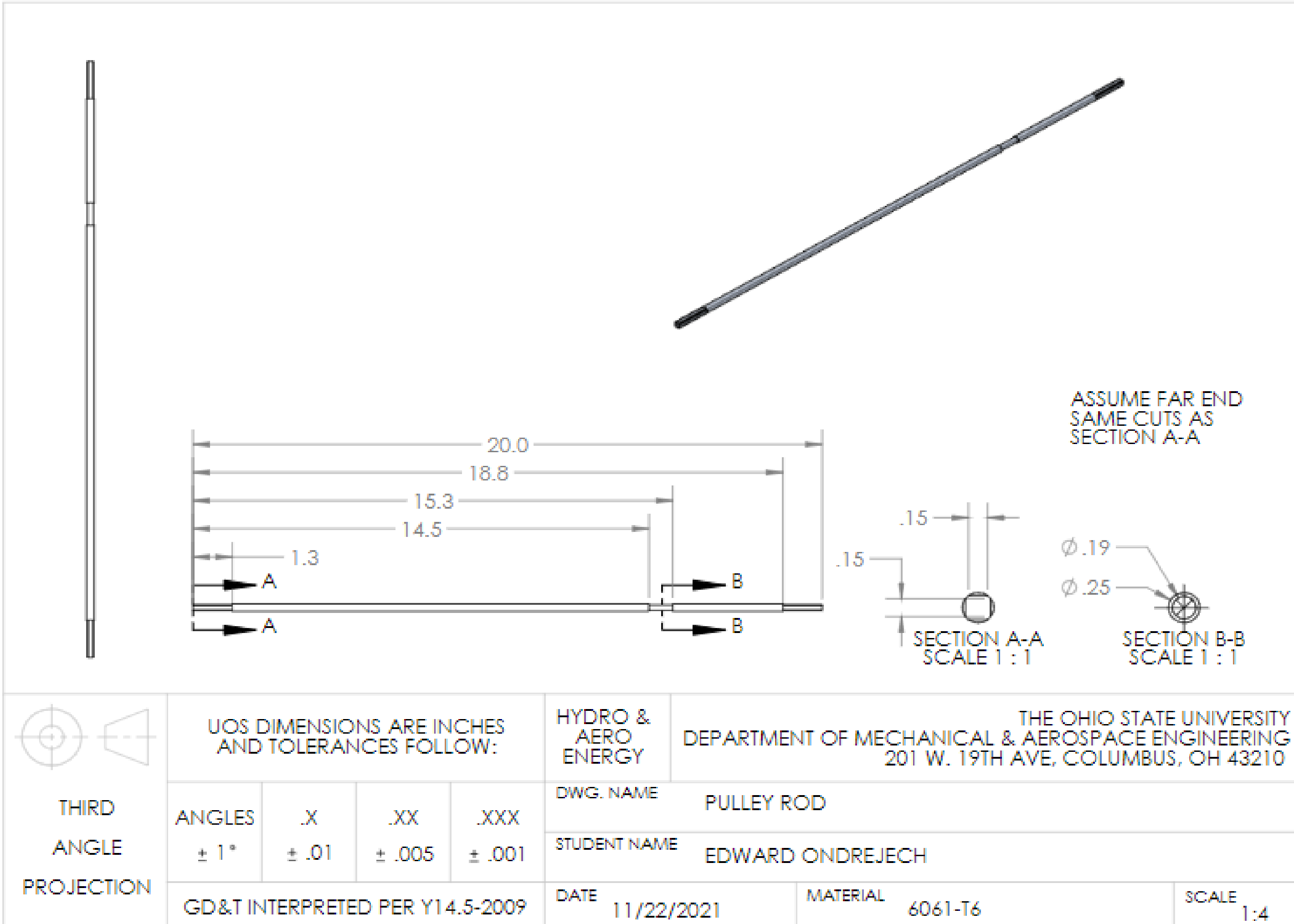

Figure A40: Pulley Rod

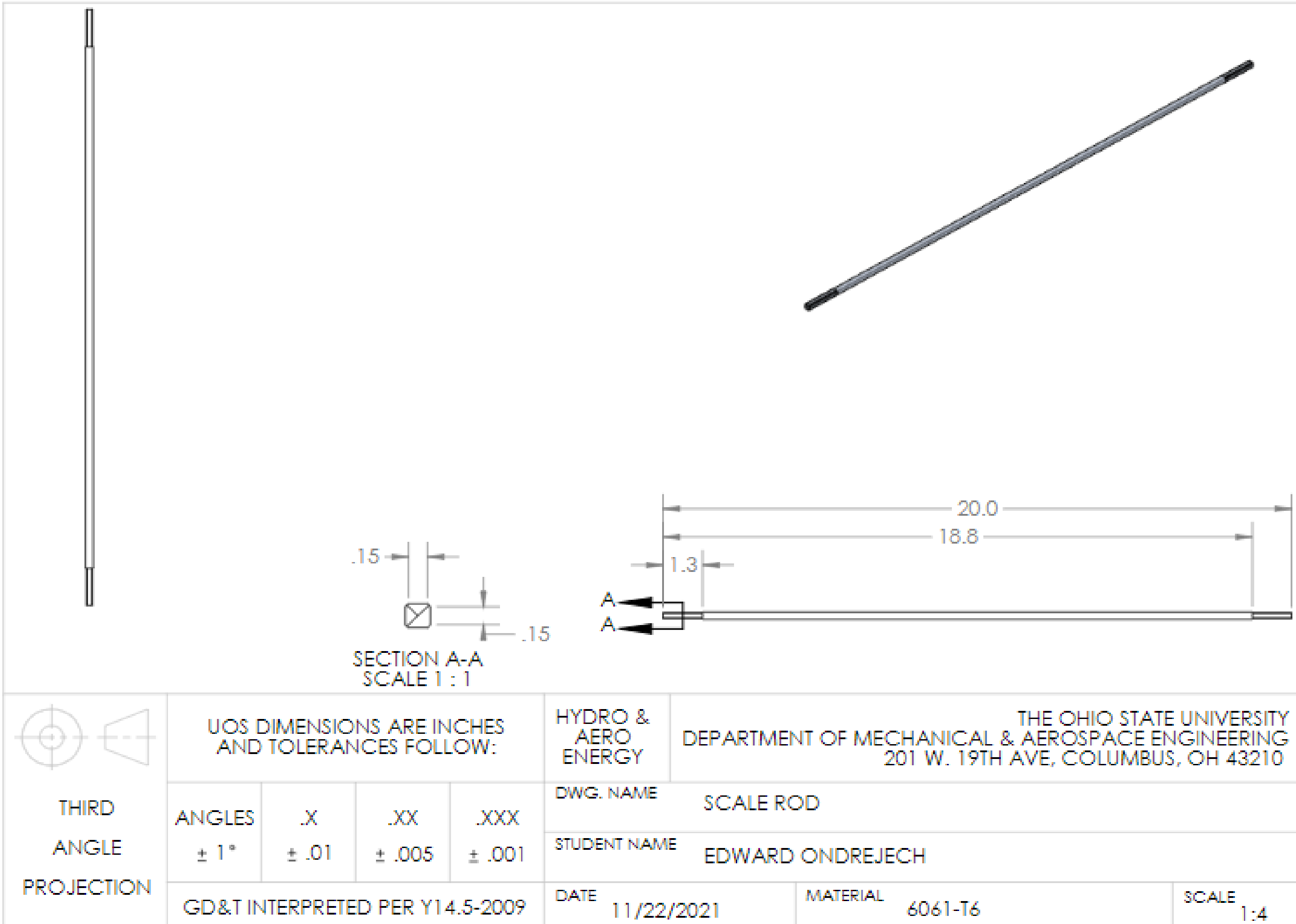

Figure A41: Scale Rod

Appendix B: Exploded Views for Assembly

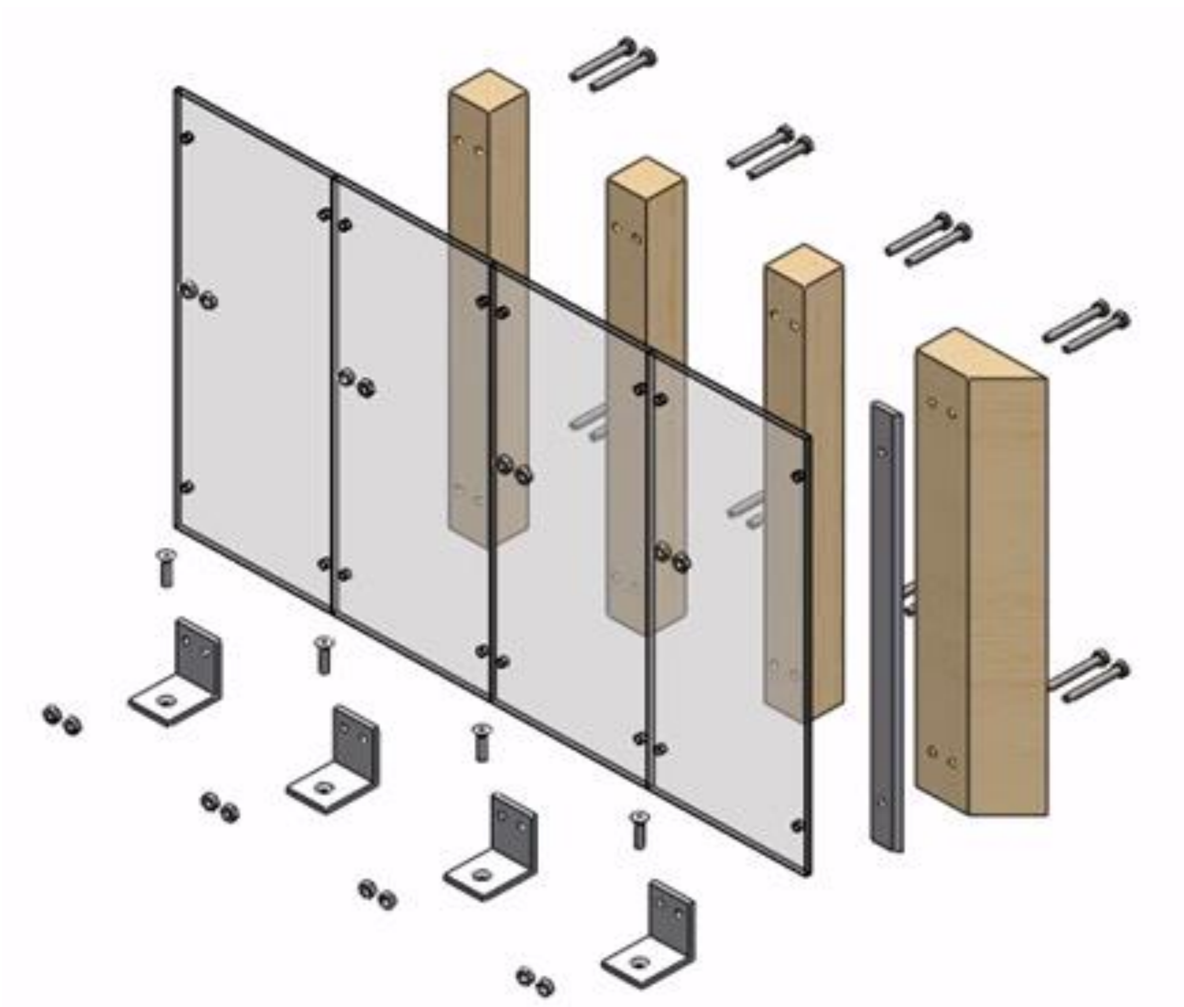

Figure B1: Diversion Assembly

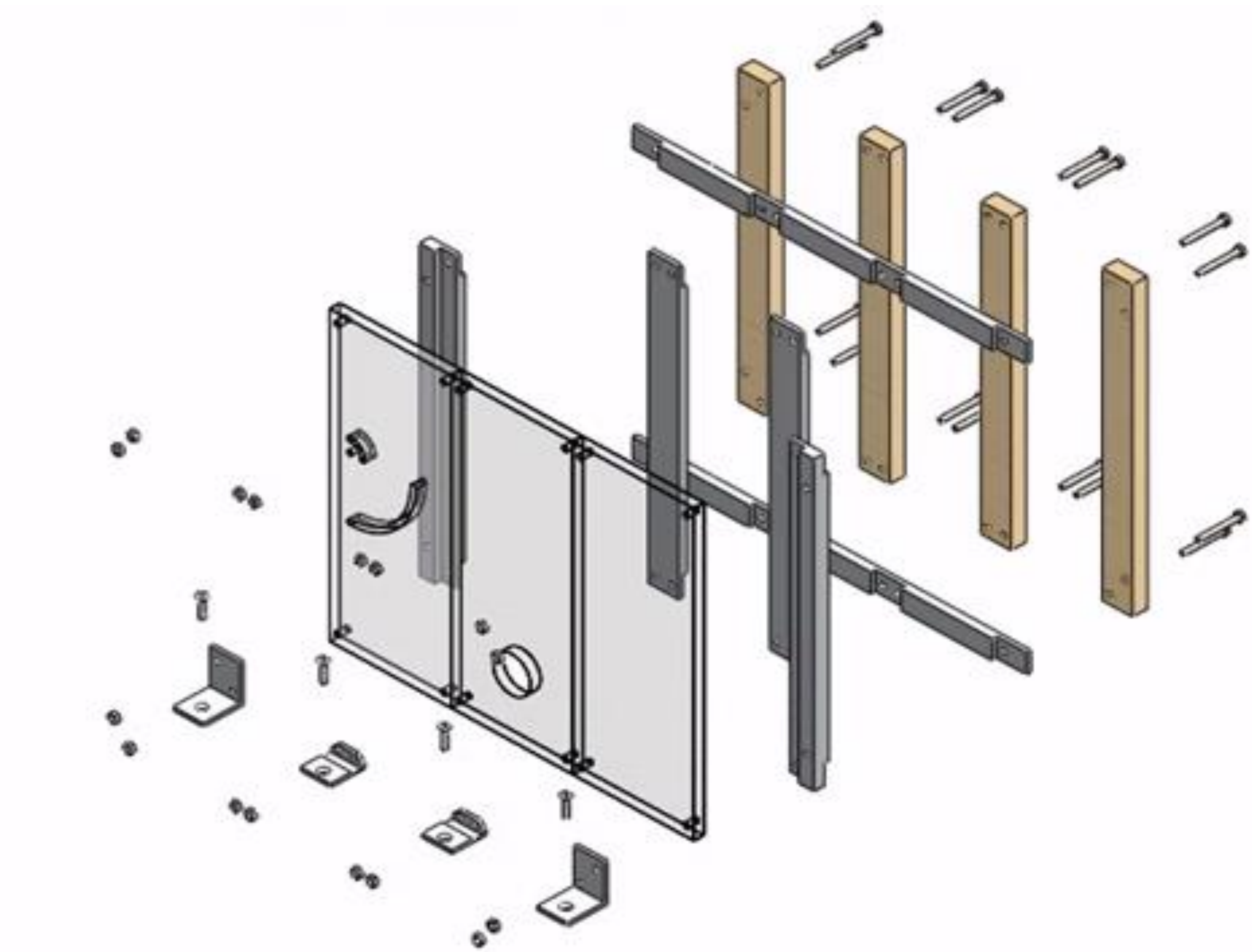

Figure B2: Casing Assembly

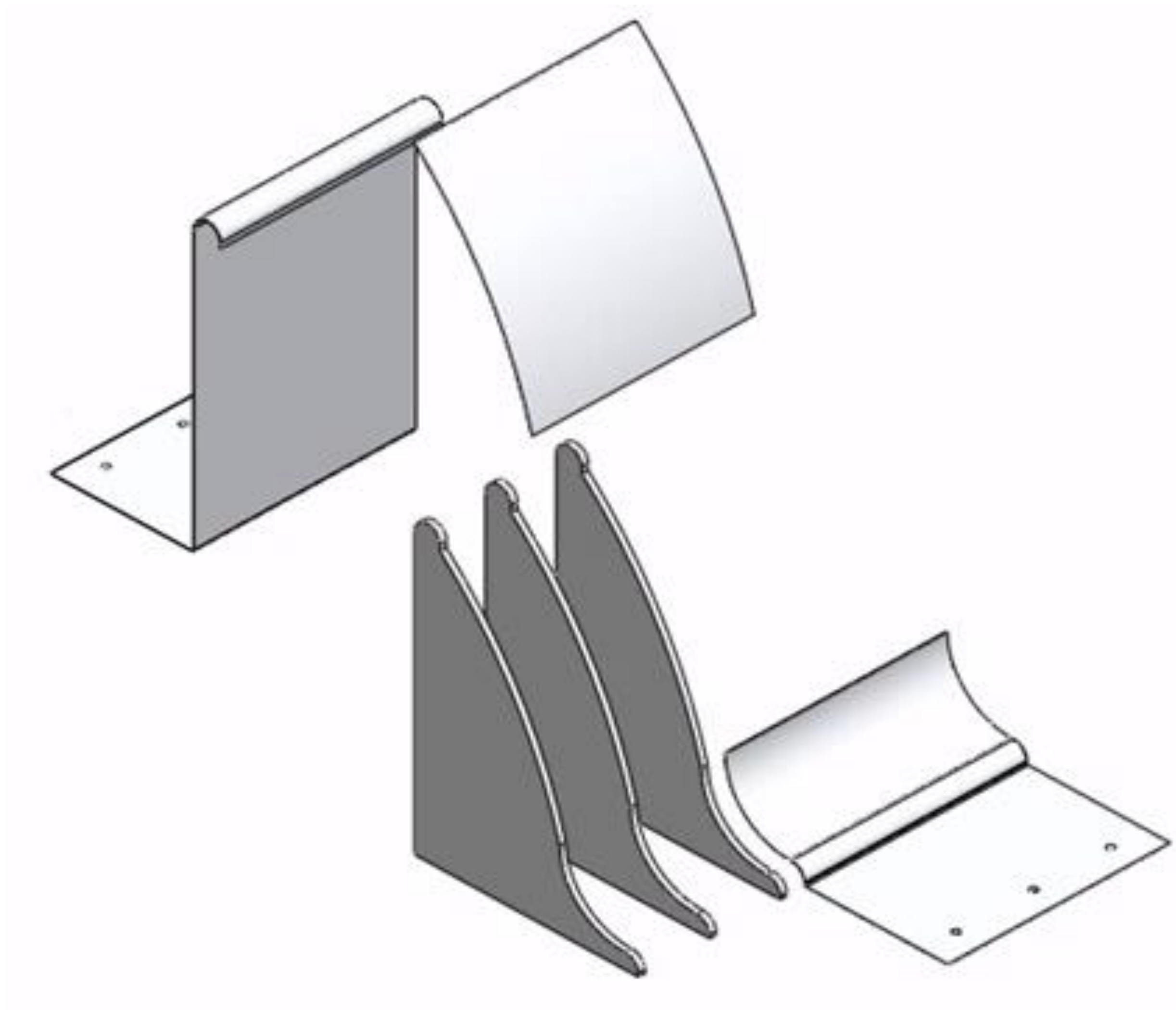

Figure B3: Weir Assembly

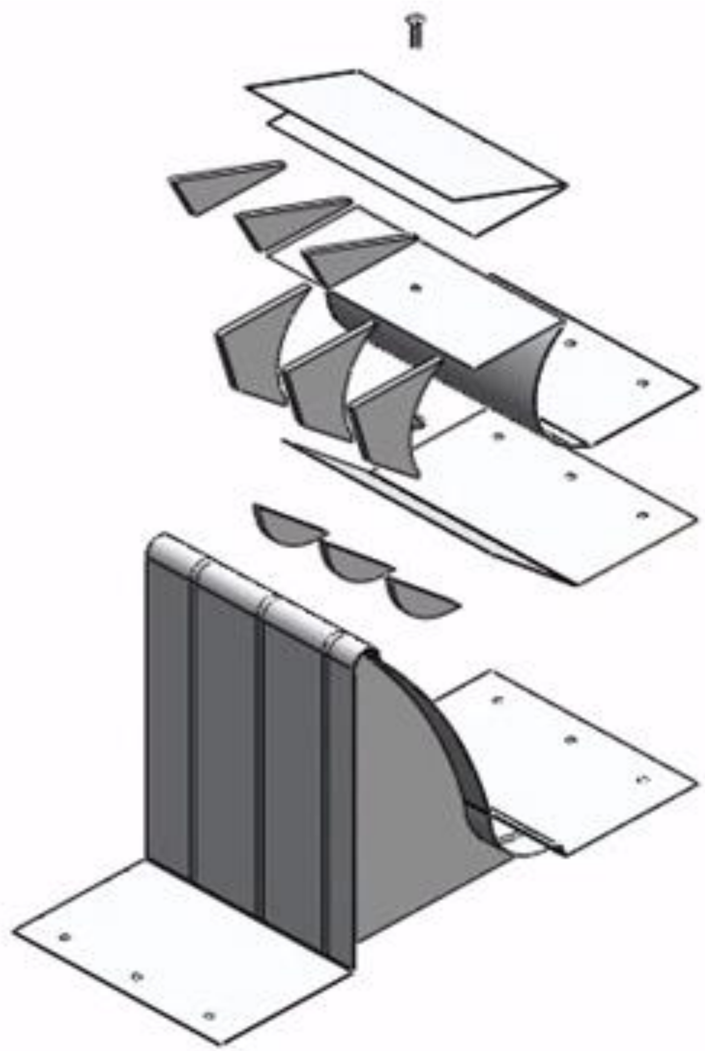

Figure B4: Inflow Assembly

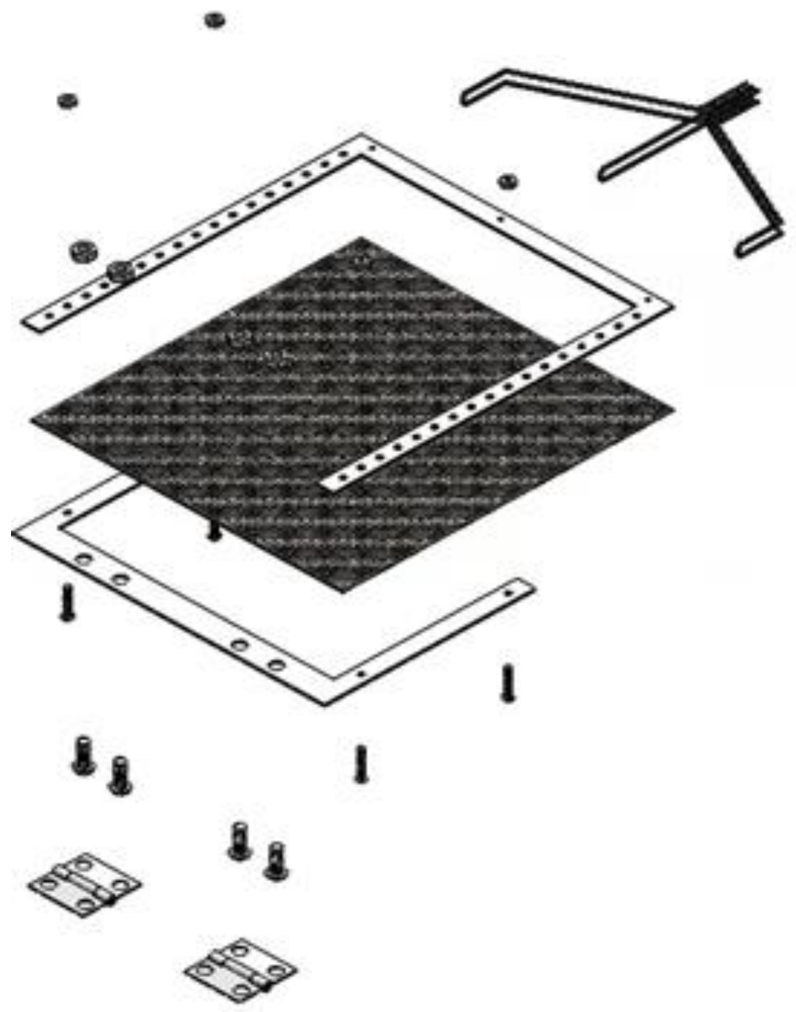

Figure B5: Screen Assembly

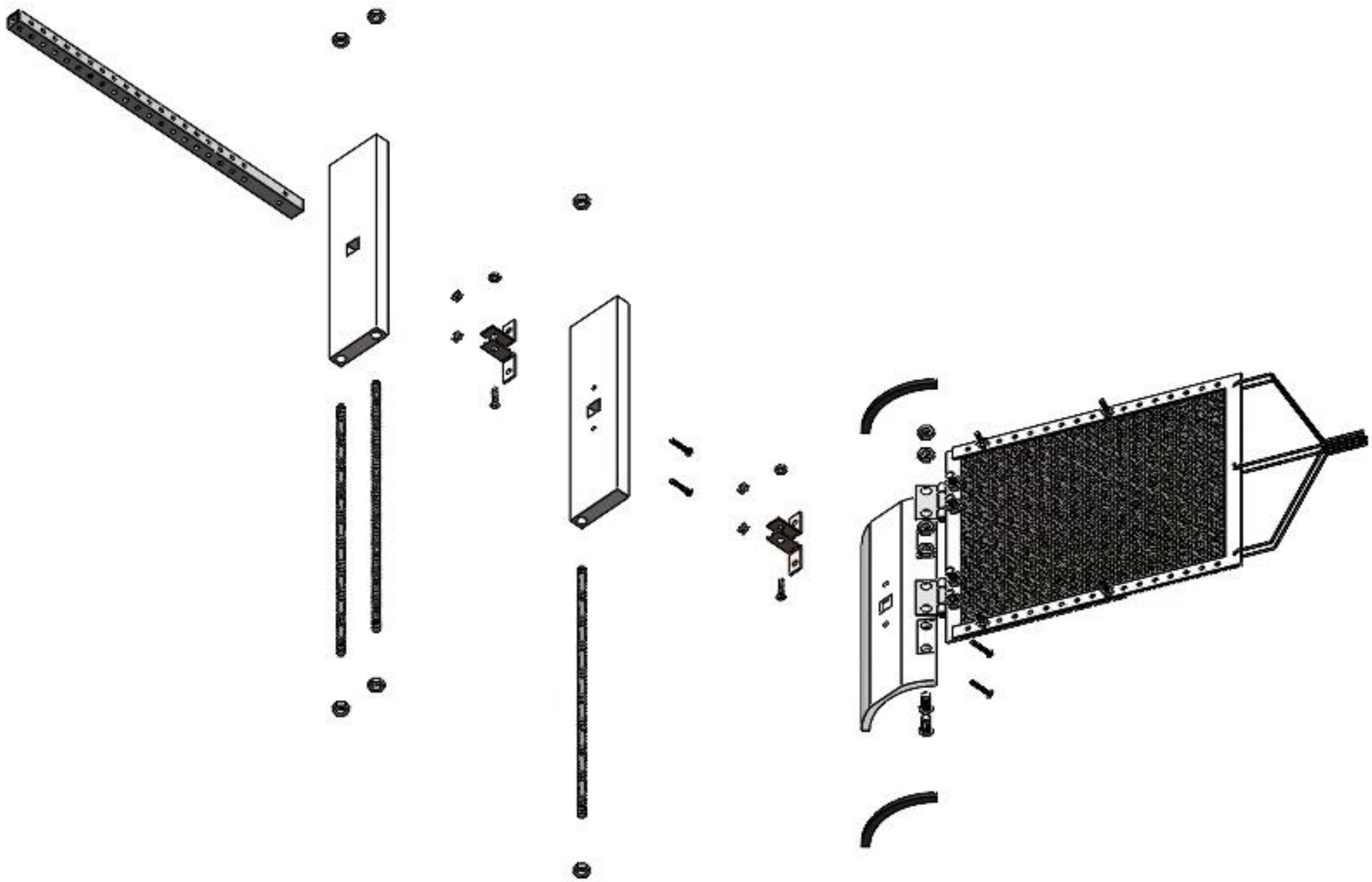

Figure B6: Outflow Assembly

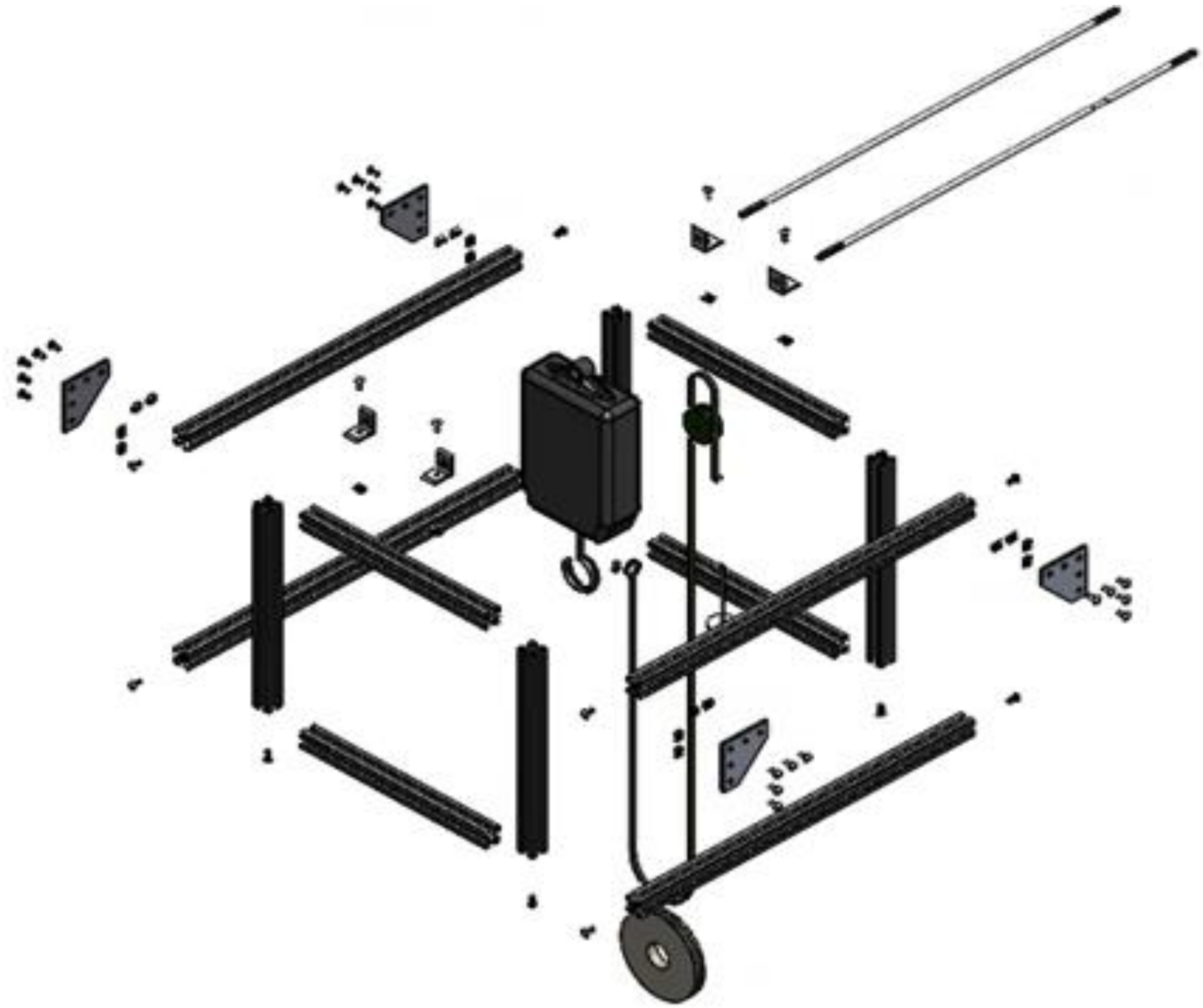

Figure B7: Overhang Assembly

Appendix C: Diversion Modeling Iterations

Figure C1: Dual Cowl Diversion Design

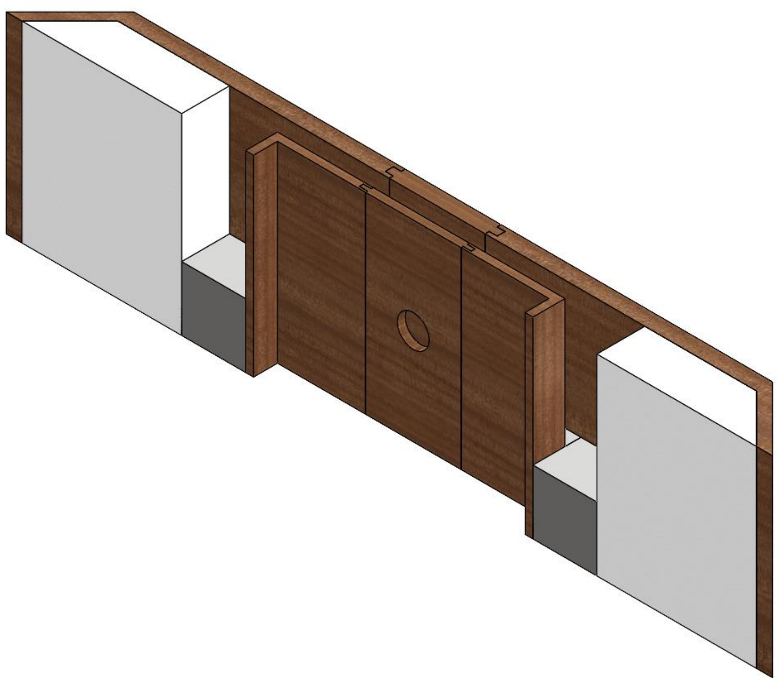

Figure C2: Dual Cowl Sponge Diversion Design

Figure C3: Movable Center Design 2

Figure C4: Original Lath Design

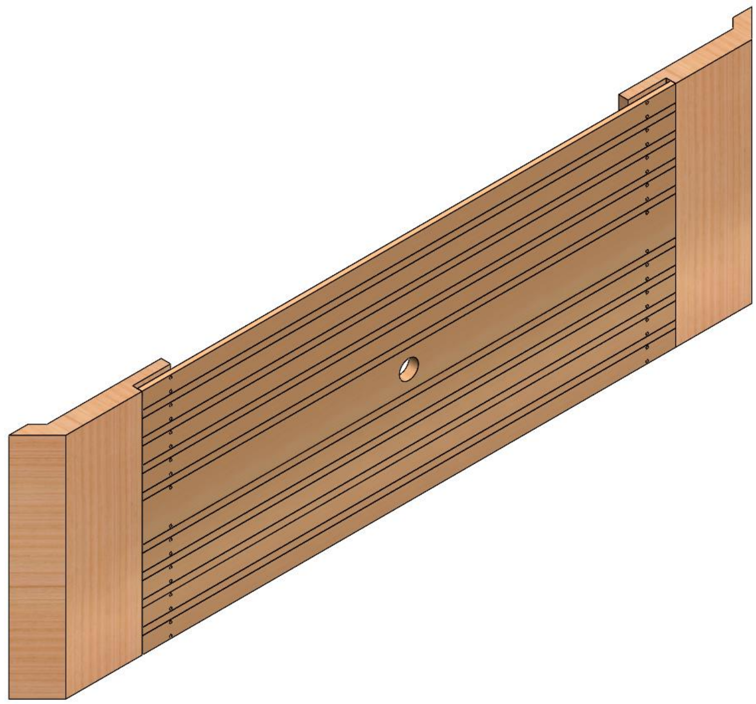

Figure C5: Original Lath Wall Design

Figure C6: Lath Diversion Second Iteration

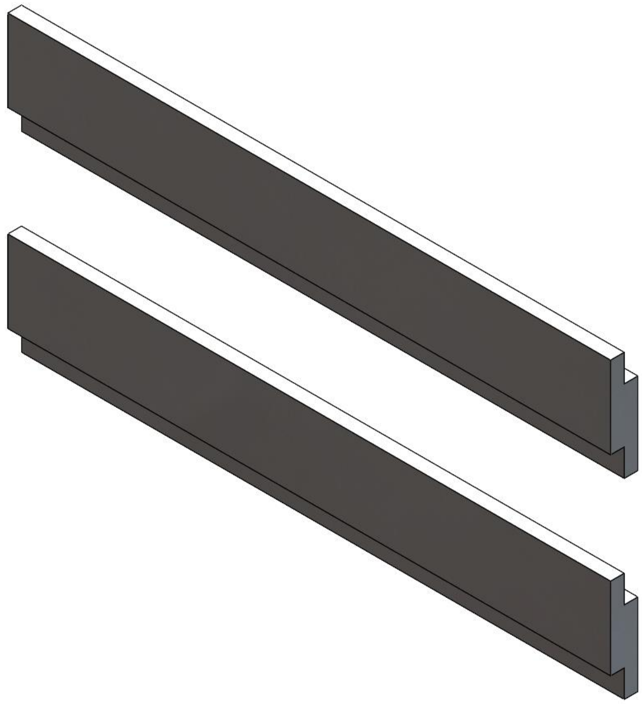

Figure C7: Lath Diversion Third Iteration

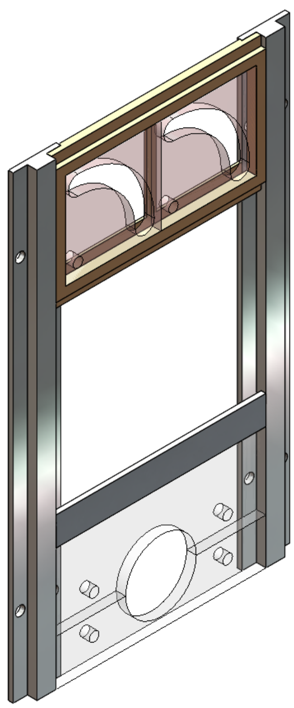

Figure C8: Lath Diversion Fourth Iteration

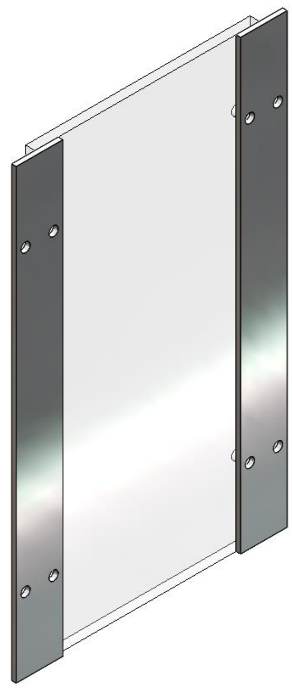

Figure C9: Diversion 6 Inch Sections

Appendix D: Weir Modeling Iterations

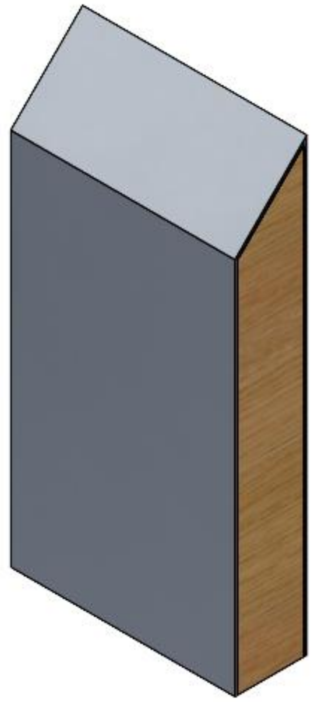

Figure D1: Solid Cross Section

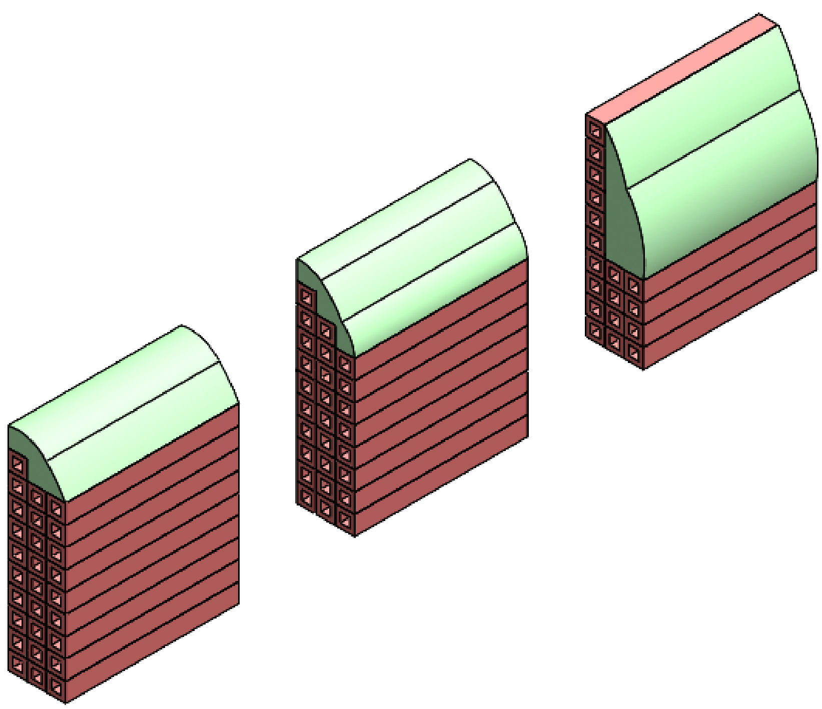

Figure D2: Foam Block Weir

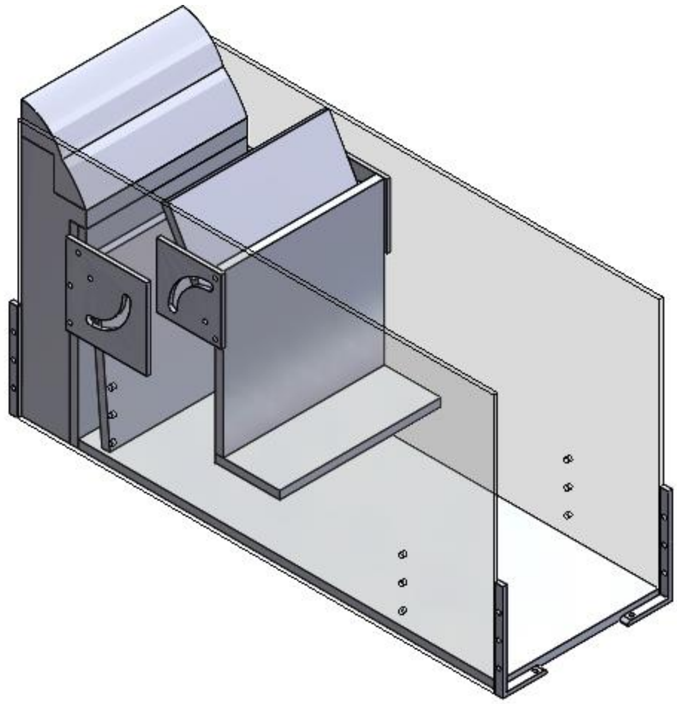

Figure D3: Interlocking Weir Design

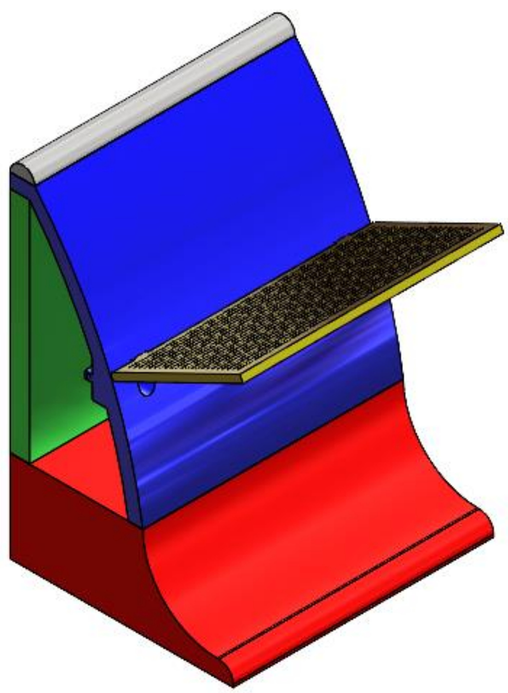

Figure D4: Screen Attachable Weir

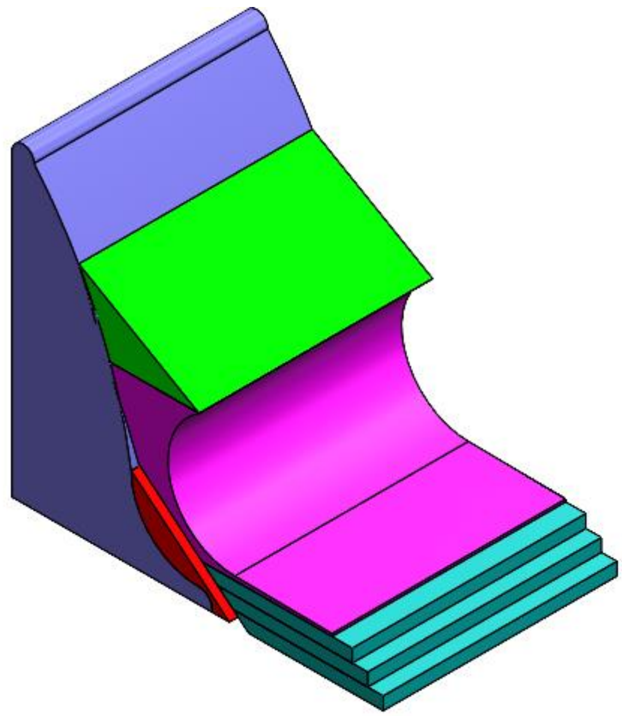

Figure D5: Adjustable Height Weir

Appendix E: Casing Modeling Iterations

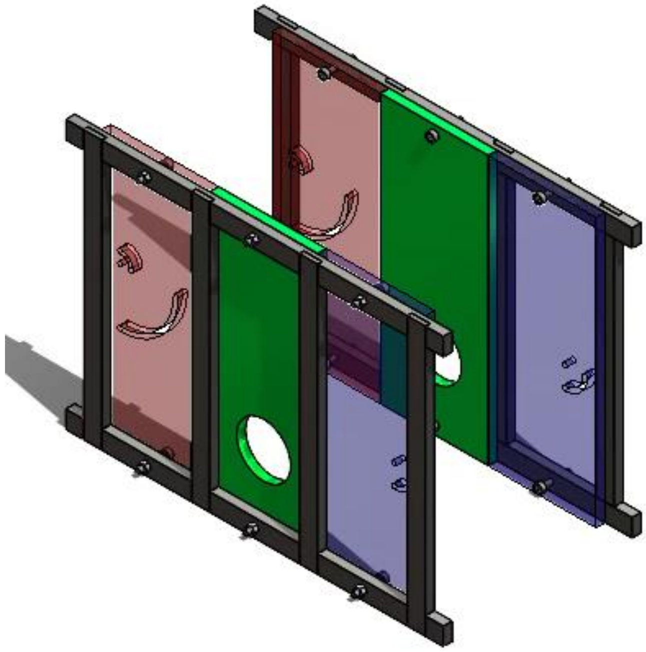

Figure E1: Casing Angling Version 1 Model

Appendix F: Raising and Lowering Modeling Iterations

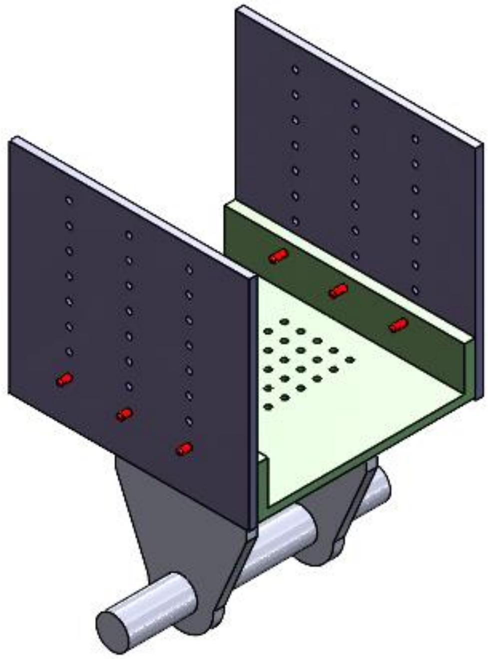

Figure F1: Pin Lowering Design

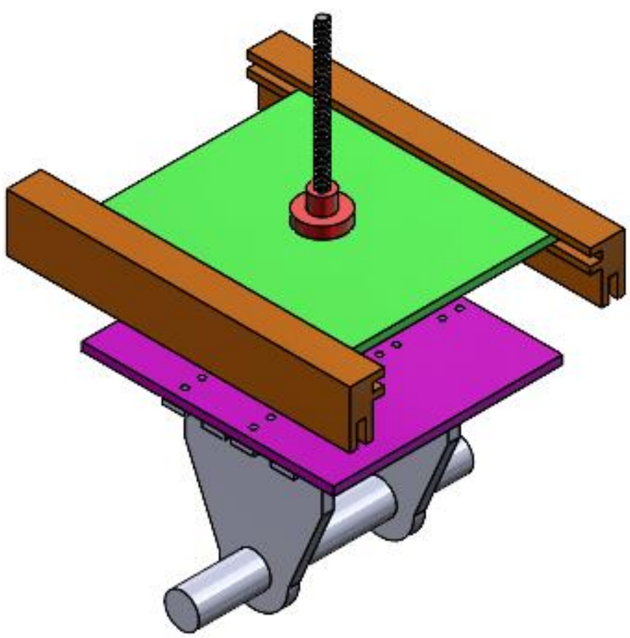

Figure F2: Lead Screw Lowering Design

Figure F3: Side Screw Lowering Design

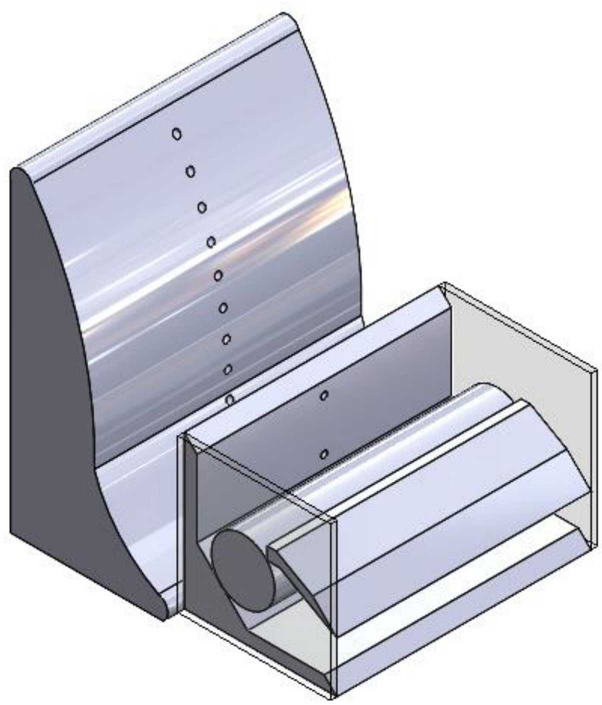

Figure F4: Weir Attached Lowering Design

Appendix G: Overhang Modeling Iterations

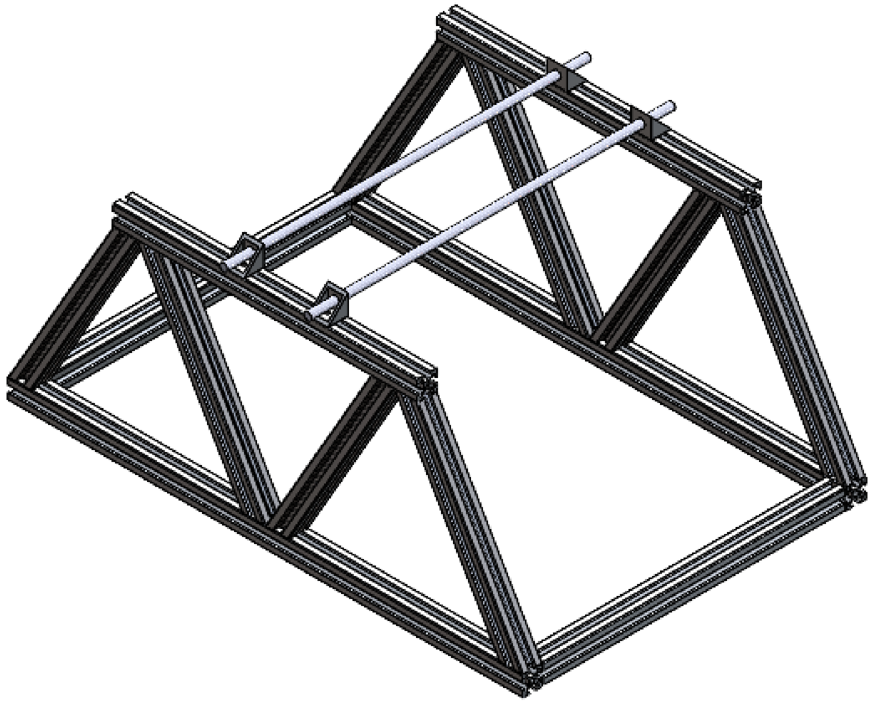

Figure G1: Initial Truss Overhang Model